Universitat de les
Illes Balears

DOCTORAL THESIS
2015

HABITATS AND NEKTO-BENTHIC COMMUNITIES OF THE BOTTOM-TRAWL FISHERY DEVELOPED ON THE CONTINENTAL SHELF OF THE BALEARIC ISLANDS

Francesc Ordinas Cerdà

Universitat de les Illes Balears

DOCTORAL THESIS
2015

Doctoral Programme of Marine Ecology

HABITATS AND NEKTO-BENTHIC COMMUNITIES OF THE BOTTOM-TRAWL FISHERY DEVELOPED ON THE CONTINENTAL SHELF OF THE BALEARIC ISLANDS

Francesc Ordinas Cerdà

Director: Dr. Enric Massutí Sureda
Representative: Dr. Rafael Bosch Zaragoza

Doctor by the Universitat de les Illes Balears

A la mar ningú hi duu res, tothom hi va a cercar...

Ramon “Durai”, pescador de Cala Sant Vicenç entre 1950 i 2001

Acknowledgements/Agraïments

Ha estat llarg això…. Però a la fi ha arribat l'hora dels agraïments. Vull donar les gràcies en primer lloc i molt especialment a na Joana i a les meves filles bessones (si poso bessones no he de triar l'ordre dels noms...). El seu recolzament, paciència i energia són una part fonamental d'aquesta tesi. Gràcies als meus pares, que amb raó es queixaren de que en anglès no entenien els treballs que he anat fent, i així i tot han cregut (ho això vull pensar) que estava fent alguna cosa de profit. Gràcies a Margalida, la meva germana, i a la resta de la família.

Gràcies a Albert Lerycke i Toni Suau per haver fet possible la campanya de censos visuals de l'estiu del 2002. Encara me pareix increïble que féssim tot aquell mostreig amb els mitjans que teníem. Aquell fou el meu primer contacte amb la recerca marina i el principi del camí que m'ha dut fins aquí. No ho oblidaré, el busseig rural marcà un punt d'inflexió!!. Qualque dia ho hem de repetir...

Gràcies a tota la gent que ha fet possible que pogués gaudir de totes les mostres, dades i informació necessària per a poder dur a terme els estudis inclosos en aquesta tesi. Moltes gràcies a tot l'equip de Recerca d'Ecosistemes i Recursos Demersals del Centre Oceanogràfic de Balears. Especialment a Enric Massutí, Beatriz Guijarro i Toni Quetglas, que han contribuït a aquesta tesi, ja sigui dirigint-la (moltes gràcies Enric), ja sigui donant suport o responent als dubtes que han anat sorgint, moltes gràcies. Gràcies a Biel Pomar, Maria Valls i Ana Morillas (moltes gràcies per les fotos Ana!). Gràcies a Joan Moranta, per deixar-me quedar aquell dia que vaig comparèixer per Esporles.

Gràcies a les tripulacions dels vaixells oceanogràfics en els que he estat de campanya.

Gràcies a Joan Jesús Vaquero i Damià Gómez (ara al V/O Francisco de Paula Navarro) de la *Punta del Vent* i a Miquel Moreno de la *Nueva Joven Josefina*, ha estat un autèntic plaer poder sortir a la mar amb vosaltres, a veure si repetim aviat!

Gràcies a Domingo Lloris i Pere Abelló de l'Institut de Ciències de la Mar, espero poder seguir aprenent de vosaltres en moltes més campanyes.

Gràcies a Francesca Cifre, i a Bernat Llobera i Lyn Tonsaker, per les revisions dels textos en català i anglès.

Gràcies a tots!

Funding

The data used in Chapter 1 comes from the EVADEM (*Evaluación de pesquerías demersales en el Mediterráneo*) and EVADEMED (*Evaluación de recursos demersales del Mediterráneo*) projects, funded by the Instituto *Español de Oceanografía* (IEO).

Part of the data used in chapters 2 and 3 comes from the MIGJORN surveys, carried out in the framework of the project *Seguimiento y evaluación de la pesca de arrastre de plataforma en el área comprendida entre Cala Rajada, Cabrera y la bahía de Palma (Este y Sur de Mallorca)*, funded by the *Conselleria d'Agricultura i Pesca del Govern de les Illes Balears* and the IEO. Chapter 3 also analyzes data coming from the EVADEM, EVADEMED, and BADEMECO (*Estudio integrado de los ecosistemas demersales explotados en las Islas Baleares (Mediterráneo occidental) y bases científico-técnicas para un enfoque ecosistémico en la gestión de pesquerías,* also funded by the IEO, and since 2007 partially funded by the European Union (EU, Data Collection Regulation and Data Collection framework)) projects, and the *Special Action of Research, Technological Development and Innovation AAEE0115/09* (*Influència dels hàbitats bentònics en la condició dels recursos demersals. Una aproximació mitjançant indicadors bioquímics*) funded by the *Conselleria d'Innovació, Interior i Justícia del Govern de les Illes Balears.*

The data used in chapter 4 comes from the MEDER (*Evaluación y bases técnicas para la gestión de las pesquerías demersales,* funded by the IEO), DEMO (*Evaluación de recursos y bases técnicas par al agestión de pesquerías demersales en el Mediterráneo occidental,* funded by the IEO), EVADEM, EVADEMED, and BADEMECO projects, and from the Data collection Regulation and Data Collection Framework, funded by the European Union and the IEO.

Chapter 5 is a result of two experimental pilot projects (RAI-AP-22-2001 and RAI-AP-6-2002) carried out under the proposal of an ownership firm (Albertí Morey, S.A.) and funded by the Secretary of Fisheries (Ministry of Agriculture, Fisheries and Food).

Structure of the PhD thesis

This PhD thesis is structured as a compendium of the published research articles listed below:

Ordines F., Massutí E. (2009). Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 370-383. doi: 10.1002/aqc.969
JCR journal ranking (acceptance date): Q1

Ordines F., Jordà G., Quetglas A., Flexas M., Moranta J., Massutí E. (2011). Connections between hydrodynamics, benthic landscape, and associated fauna in the Balearic Islands, western Mediterranean. *Continental Shelf Research* 31: 1835-1844. doi: 10.1016/j.csr.2011.08.007
JCR journal ranking (acceptance date): Q2

Ordines F., Quetglas A., Massutí E., Moranta J. (2009). Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. *Estuarine, Coastal and Shelf Science* 85: 537-546. doi: 10.1016/j.ecss.2009.09.020
JCR journal ranking (acceptance date): Q1

Ordines F., Bauzá M., Sbert M., Roca P., Gianotti M., Massutí E. (2014). Red algae beds increase the condition of nekto-benthic fish. *Journal of Sea Research* 95: 115-123. doi: 10.1016/j.seares.2014.08.002
JCR journal ranking (acceptance date): Q2

Ordines F., Farriols M.T., Lleonart J., Guijarro B., Quetglas A., Massutí E. (2014). Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean. *Mediterranean Marine Science*, 15: 613-625. doi: 10.12681/mms.812
JCR journal ranking (acceptance date): Q2

Ordines F., Massutí E., Guijarro B., Mas R (2006). Diamond *vs.* squared mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquatic Living Resources* 19: 329-338. doi: 10.1051/alr:2007003
JCR journal ranking (acceptance date): Q2

Table of contents

Abbreviations and acronyms

AX1 and **AX2**: first and second axis of the Principal components analysis

C: concentration of lipids or proteins in the liver or gonad in mg per g of tissue

CB: Crinoid beds

CV: coefficient of variation

DI: Diamond mesh

DS: Deep shelf

DSM: deep shelf sandy-mud bottoms

DW: Digestive tract weight

EAF: Ecosystem Approach to Fisheries

EBFM: Ecosystem-based fisheries management

EU: European Union

EW: Eviscerated weight

F: Fishing mortality

FAO: Food and Agriculture Organisation

FP: Feeding potential

$\mathbf{FP_m}$: Mean feeding potential per haul

FS: Fishing strategy

F_t: Terminal fishing mortality

GSA: Geographic sub-areas of the General Fisheries Commission for the Mediterranean

GSI: Gonadosomatic index

GW: Gonad weight

HC: Hepatic condition

$\mathbf{HC_m}$: Mean hepatic condition per haul

I: index

k: instantaneous growth coefficient

L: length class

L_{50}: size at first maturity

L_∞: Length infity or the asymptotic length at which growth is zero

LCA: Length Cohort Analysis

LGSI: Lipid gonadosomatic index

LHSI: Lipid hepatosomatic index

L_t: Total length at age t

LW: Liver weight

M: Natural death

MANCOVA: Multivariate analysis of covariance

MANOVA: Multivariate analysis of variance

MB: Maërl beds

MDS: Non-metric multi-dimensional scaling

MFC: Mixed fish comercial category

MLS: Minimum landing size

OPMALLORCAMAR: Organització de Productors MallorcaMar (Producers Organization in Mallorca)

PB: Peyssonnelia beds

PCA: Principal components analysis

PGSI: Protein gonadosomatic index

PHSI: Protein hepatosomatic index

PL: Proportion of mature individuals for a given size class L

RC: Reproductive condition

RDA: Redundancy analysis

$\overline{S_i}$ **:** average similarity

S₁ and ***S₂***: Parameters of the logistic selection curve

SC: Somatic condition

SC_m: Mean somatic condition per haul

SD: Standard deviation

SIMPER: Similarity percentage analysis

SL: The retention probability of individuals that entered in the codend

SL_{25}: length at which the probability of being retained in the codend is 25%

SL_{50}: length at which the probability of being retained in the codend is 50%

SL_{75}: length at which the probability of being retained in the codend is 75%

SNK: Student-Newman-Keuls post-hoc test

SQ: Square mesh

SR: Selection range

SS: Shallow shelf

SSB: Spawning stock biomass

STECF: Scientific, Technical and Economic Commitee for Fisheries

t_0: hypothetical age at which length is equal to zero.

TL: Total length

TML: Talla minima legal

TsW: total tissue weight in g

TW: Total weight

$\bar{U}$: Mean water velocity

V: Commercial value

VBGF: von Bertalanffy growth function

VMS: Vessel Monitoring Satellite System

VPA: Virtual Population Analysis

$\overline{Y}$: mean yields

Y/R: Yield per recruit

Y/R_{max}: maximum sustainable yield

$Y/R_{F0.1}$: yield per recruit at a fishing mortality rate corresponding to 10% of the slope of the yield-per-recruit curve at the origin

Φ: effort factor

$\Phi_{F0.1}$: Effort factor corresponding to the and $Y/R_{F0.1}$

Φ_{max}: effort factor corresponding to the Y/R_{max}

% $\overline{S_i}$: percentage contribution to the similarity

Summary

Introduction

The presence of biogenic benthic habitats in the continental shelf of the Balearic Islands is well known. In the circalittoral, outstanding due to their presence, the following can be found: the bottoms of calcareous red algae of the Corallinaceae family (known as maërl beds), considered particularly sensitive to the anthropogenic impacts; the crinoids beds, considered an essential habitat for the vital cycle of the fishing resources; or the *Peyssonnelia* beds, characterized by high biomasses of soft red algae, mainly of the *Peyssonnelia* genus. The bottom trawl fishery, developed in the continental shelf of the Archipelago takes place in these types of bottoms. In spite of this, and the negative effects of bottom trawling on benthic habitats, in the Balearic Islands, there is little information on the relationships between these habitats and the exploited species, whose biology and exploitation state is also unknown for the majority.

Research contents

This doctoral thesis studies the benthic habitats and the nekto-benthic communities exploited by the bottom trawl fishery developed on the continental shelf of the Balearic Islands. The main objectives include determining: the relationship between habitats and fishing resources, the main factors affecting the distribution of both, and how the presence of the main biogenic habitats affects the physiological condition of the associated fish species characterizing them. For the first time, the biology and exploitation state of some of the fishing resources characterizing these bottoms is studied, as well as the effect of changing the mesh geometry in the codend of the bottom trawl gears, from diamond to square, on the selectivity of this fishery.

The results highlight that the presence of maërl and *Peyssonnelia* beds in the bottom trawl fishing grounds of the shallow shelf, and the crinoid beds in those of the deep shelf, is an important factor for the distribution of nekto-benthic fishing resources. Hydrodynamics influence the distribution of both habitats and fish. In this sense, fish size appears as a key trait for their distribution across gradients of change of both habitat and hydrodynamic regime.

The study of the biology of characteristic fish species of the shallow shelf indicates that the most structurally complex biogenic habitats, showing the highest algae biomasses, such as maërl and *Peyssonnelia* beds, allow the individuals inhabiting them to have a better physiological condition than those distributed in habitats showing lower structural complexity and benthic biomass, such as the sandy bottoms.

The main by-catch species of the bottom trawl fishery developed in the continental shelf of the Balearic Archipelago show a similar, or even more pronounced, level of overexploitation than the main target species of this fishery, which are the striped red mullet (*Mullus surmuletus*) and the hake (*Merluccius merluccius*). The use of square mesh in the codend substantially

improves the selectivity of the bottom trawl gears, reducing the discarded catch and increasing the size at first capture of most species. However, these sizes are still smaller than the size of sexual maturity of most species, and in some cases, even smaller than the minimum landing sizes.

Conclusion

The results highlight the importance of the presence of the biogenic benthic habitats for the populations of nekto-benthic organisms. Some of these habitats can play the role of oases where fish could face the energetic requirements of their vital cycle in a better physiological condition. In the Balearic Sea, an area standing out by its oligotrophy and where the most important commercial species show signs of overexploitation, the sustainability of fishing resources will depend on the ability to implement management measures aiming beyond the improvement of the current exploitation regime. They will have to take into account key aspects of the vital cycle of these species and the conservation of the habitats supporting them.

Resum

Introducció

La presència d'hàbitats bentònics biogènics a la plataforma continental de les Illes Balears és ben coneguda. Al circalitoral hi destaquen per la seva presència: els fons d'algues vermelles calcàries de la família de les coral·linàcies (coneguts com a *maërl*), considerats especialment sensibles als impactes antropogènics; els fons de crinoïdeus, considerats un hàbitat essencial pel cicle vital dels recursos pesquers; o els fons d'*avellanó*, caracteritzats per presentar biomasses elevades d'algues vermelles toves, principalment del gènere *Peyssonnelia*. La pesquera de ròssec que es desenvolupa a la plataforma continental de l'Arxipèlag coincideix amb aquests tipus de fons. Malgrat això i els efectes negatius del ròssec sobre els hàbitats bentònics, a les Balears existeix poca informació sobre les relacions entre aquests hàbitats i les espècies explotades, de les quals tampoc se'n coneix la biologia i estat d'explotació de la majoria.

Contingut de la investigació

Aquesta tesi doctoral estudia els hàbitats bentònics i les comunitats necto-bentòniques explotats per la pesquera de ròssec de la plataforma continental de les Illes Balears. Els principals objectius són determinar com es relacionen hàbitats i recursos pesquers, quins són els principals factors que afecten la distribució d'ambdós, i com afecta la presència dels principals hàbitats biogènics a la condició fisiològica d'algunes de les espècies de peixos que els caracteritzen. També s'estudia per primer cop la biologia i estat d'explotació d'alguns dels recursos pesquers característics d'aquests fons, així com l'efecte del canvi de la geometria de la malla del cop de les xarxes de ròssec, de ròmbica a quadrada, sobre la selectivitat d'aquesta pesquera.

Els resultats destaquen que la presència dels fons de maërl i de *Peyssonnelia* als caladors de ròssec de la plataforma costanera, i els de crinoïdeus als de la plataforma profunda, actua com a un factor important per a la distribució dels recursos pesquers necto-bentònics. La hidrodinàmica condiciona tant la distribució dels hàbitats com la dels peixos. En aquest sentit, la mida dels peixos apareix com una característica clau en la seva distribució a través de gradients de canvi d'ambdós, hàbitat i règim hidrodinàmic.

L'estudi de la biologia d'espècies íctiques característiques de la plataforma costanera, indica que els hàbitats biogènics estructuralment més complexes i amb major biomassa algal, com els de maërl i *Peyssonnelia*, permeten als individus que hi habiten gaudir d'una millor condició fisiològica que els que es distribueixen a hàbitats menys complexes i amb menor biomassa bentònica, com els fons de sorra.

Les principals espècies 'by-catch' de la pesquera de ròssec que es desenvolupa a la plataforma continental de l'Arxipèlag Balear es troben en un nivell de sobreexplotació semblant, o inclús més pronunciat, que les principals espècies objectiu d'aquesta pesquera, el moll (*Mullus surmuletus*) i el lluç (*Merluccius merluccius*). La utilització de malla quadrada al cop suposa una

clara millora en la selectivitat dels arts de ròssec, reduint la captura rebutjada i augmentant la talla de primera captura de la majoria d'espècies. Tot i així, aquestes talles segueixen essent menors que la talla de maduresa sexual de la majoria d'espècies, i en alguns casos, fins i tot menors que les talles mínimes legals.

Conclusió

Els resultats remarquen la importància que té la presència dels hàbitats bentònics biogènics per a les poblacions d'organismes necto-bentònics. Alguns d'aquests hàbitats poden actuar com a oasis que permetrien als peixos afrontar amb una millor condició fisiològica els requeriments energètics del seu cicle vital. Al Mar Balear, una àrea que destaca per la seva oligotròfia i on les poblacions de les principals espècies comercials mostren signes de sobreexplotació, la sostenibilitat dels recursos pesquers dependrà de la capacitat d'implementar mesures de gestió amb objectius més enllà de la millora del règim d'explotació actual. Hauran de tenir en compte aspectes clau del cicle vital d'aquestes espècies i la conservació dels hàbitats que els hi donen suport.

Resumen

Introducción

La presencia de hábitats bentónicos biogénicos en la plataforma continental de las Illes Balears es bien conocida. En el circalitoral destacan por su presencia: los fondos de algas rojas calcáreas de la familia de las coralináceas (conocidos como *maërl*), considerados especialmente sensibles a los impactos antropogénicos; los fondos de crinoideos, considerados un hábitat esencial para el ciclo vital de los recursos pesqueros; o los fondos de *avellanó,* caracterizados por presentar biomasas elevadas de algas rojas blandas, principalmente del género *Peyssonnelia*. La pesquería de arrastre que se desarrolla en la plataforma continental del Archipiélago coincide con estos tipos de fondo. A pesar de ello y de los efectos negativos del arrastre sobre los hábitats bentónicos, en las Baleares existe poca información sobre las relaciones entre éstos hábitats y las especies explotadas, de las cuáles tampoco se conoce la biología y estado de explotación de la mayoría.

Contenido de la investigación

Esta tesis doctoral estudia los hábitats bentónicos y las comunidades necto-bentónicas explotados por la pesquería de arrastre de la plataforma continental de las Illes Balears. Los principales objetivos son determinar cómo se relacionan hábitats y recursos pesqueros, cuáles son los principales factores que afectan la distribución de ambos y cómo afecta la presencia de los principales hábitats biogénicos a la condición fisiológica de las especies de peces que los caracterizan. También se estudia por primera vez la biología y estado de explotación de algunos de los recursos pesqueros característicos de estos fondos, así como el efecto del cambio de la geometría de la malla del copo de las redes de arrastre, de rómbica a cuadrada, sobre la selectividad de esta pesquería.

Los resultados destacan que la presencia de los fondos de maërl y de *Peyssonnelia* en los caladeros de arrastre de la plataforma costera, y los de crinoideos en los de la plataforma profunda, actúa como un factor importante para la distribución de los recursos pesqueros necto-bentónicos. La hidrodinámica condiciona la distribución tanto de hábitats como de peces. En este sentido, el tamaño de los peces aparece como una característica clave para su distribución a través de gradientes de cambio de ambos, hábitat y régimen hidrodinámico.

El estudio de la biología de especies ícticas características de la plataforma costera, indica que los hábitats biogénicos estructuralmente más complejos y con mayor biomasa algal, como los de maërl y *Peyssonnelia*, permiten que los individuos que los habitan disfruten de una mejor condición fisiológica que los que se distribuyen en hábitats menos complejos y con menor biomasa bentónica, como los fondos de arena.

Las principales especies ‘by-catch’ de la pesquería de arrastre que se desarrolla en la plataforma continental del Archipiélago Balear se encuentran en un nivel de sobreexplotación similar, o incluso más pronunciado, que las

principales especies objetivo de esta pesquería, el salmonete (*Mullus surmuletus*) y la merluza (*Merluccius merluccius*). La utilización de malla cuadrada en el copo supone una clara mejoría en la selectividad de los artes de arrastre, reduciendo la captura descartada y aumentando la talla de primera captura de la mayoría de especies. Aún así, estas tallas siguen siendo menores que la talla de madurez sexual de la mayoría de especies, y en algunos casos, incluso inferiores a la talla mínima legal.

Conclusión

Los resultados remarcan la importancia que tiene la presencia de los hábitats bentónicos biogénicos para las poblaciones de organismos necto-bentónicos. Algunos de estos hábitats pueden actuar como oasis que permitirían a los peces afrontar con una mejor condición fisiológica los requerimientos energéticos de su ciclo vital. En el Mar Balear, un área que destaca por su oligotrofia y donde las poblaciones de las principales especies comerciales muestran signos de sobreexplotación, la sostenibilidad de los recursos pesqueros dependerá de la capacidad de implementar medidas de gestión con objetivos más allá de la mejora del régimen de explotación actual. Deberán tener en cuenta aspectos clave del ciclo vital de estas especies y la conservación de los hábitats que las sustentan.

INTRODUCTION

Introduction

The first complaints about the impact of bottom trawl fishing date from the XIV century. In the year 1376 British fishermen using other fishing gears raised their concerns about the negative effects of bottom trawling on their fisheries to the Parliament. They were convinced that it destroyed the fauna and flora of the bottom of the sea, and was detrimental to small fish and non commercial species (Messieh et al., 1991; Jones, 1992). The same concerns repeated again in the XVII century in the western Mediterranean, as reported in the work *Observaciones sobre la pesca llamada de parejas de bou: Utilidad y necesidad de su uso en el Golfo de Valencia*, written in 1866. This document explains the conflicts of interests between fishermen using different gears and those dedicated to the bottom trawl fishing in the Gulf of Valencia. It also reviews the arguments against the practice of bottom trawling listed in previous works, such as that of Duhamel du Monceau, *Traité Génèral des Pesches*, written in 1769, in which the bottom trawl fishing is qualified as a highly detrimental activity due to the use of large nets and small meshes, heavily leaded,which when towed through the bottom “raise up and disrupt it”, “pull up the herbs” and do not allow any small fish to escape, causing fish scarcity in the bottoms where this fishery is developed. The previously mentioned work also presents some arguments addressed to try to refute the previous ones, such as: the economic benefit of the bottom trawl fishery, the increase of fish supplies, and the perception, after one century since the start of this fishing activity, that the more bottom trawl boats there were, the higher the fish abundance was in the fishing bottoms for both bottom trawl boats and boats using other fishing gears.

Nowadays, a large amount of scientific information gives evidence that bottom trawl fishing (from now on, this term will refer to the fishing activity which uses a bottom trawl gear and not other types of gears towed through the bottom, e.g. beam trawl) has a considerable negative impact on marine ecosystems. The bottom trawl gears (Figure I) scrape and plough the bottom, cause sediment resuspension, and extract and physically destroy the flora and fauna of the benthos (Jones, 1992), leading to reduced production, biomass and biodiversity of the exploited bottoms, as well as changes in the structure of their benthic communities (Engel and Kvitek, 1998; Smith et al., 2000; Hiddink et al., 2006; Hinz et al., 2009).

Bottom trawling decreases the abundance of those individuals that, with their growth and/or action can create habitats. These are known as *habitat engineers,* and are mainly sessile organisms with an important vertical development, but also include organisms that can modify the substrate (Jones et al., 1994). The loss of these organisms leads to benthic communities being dominated by infauna organisms with a faster growth, and reduces three dimension structural complexity and productivity (Jennings and Kaiser, 1998; Kaiser et al., 2000; Jennings et al., 2001; Coleman and Williams, 2002; Kaiser et al., 2006; Engel and Kvitek, 1998; Mangano et al., 2013). The mega-zoobenthos organisms most vulnerable to bottom trawl fishing, those with lower resilience and slower recovering rates such as corals, are the first to face a reduction of their abundance or even disappearance from exploited bottoms (Pitcher et al., 2000; Fossa et al., 2002; Roberts, 2002). Similarly, the most

vulnerable and slow-growing species of the flora such as the free-living red Corallinaceae algae forming the maërl beds, undergo similar consequences (Bordehore et al., 2003).

These marine *habitat engineers* do not add to marine bottoms the structural complexity provided by their terrestrial homologous, the forest vegetation. However, this complexity is equally essential to preserve the biodiversity, a fact that has led to compare bottom trawl fishing effects to those of forest clear-cutting (Watling and Norse, 1998).

In any case, the direct impact of bottom trawling not only affects benthic species. The low selectivity of this fishing practice causes collateral damages on the nekto-benthic species as well, regardless of whether they are or they are not commercial targets. Hence, the discards of non-commercial species, which can include sharks, rays and skates, and other vulnerable species, or individuals of commercial species below the minimum landing size, can represent a high proportion of the catch. It is even more frequent in areas where along with a high abundance of immature individuals there are also present a high number of species, as it is the case of the bottom trawl fishery of the Mediterranean Sea (e.g. Moranta et al., 2008; Stergiou et al., 1997; Sánchez et al., 2004).

Along with the unwanted catches, there are other impacts even more difficult to be quantified. This is the case of the mortality affecting the individuals that are able to escape, which depends on both the characteristics of the species and the gears used, and which can range between the 0 and the 100%, for the most vulnerable species (Broadhurst et al., 2006). The only studies on the survival of the individuals escaping from the nets in the Mediterranean have been conducted in Turkey and estimated survival rates between 50 and 100% for some coastal continental shelf species (Metin et al., 2004; Düzbastılar et al., 2010a, 2010b).

Moreover, a lot of nekto-benthic species (including those that are the target of the fisheries) depend, directly or indirectly, on the production of the benthic communities, as they feed on benthic invertebrates or on preys that find their food resources in the benthic production (Konstantinov et al., 1985; Messieh et al., 1991). Hence, it is expected that the productivity reduction of the benthic communities affected by bottom trawl fishing activities will subsequently decrease the food resources available to nekto-benthic species, which will finally experience a negative effect on their physiological condition (Hiddink et al., 2011). Among the effects of decreased individual condition on the populations, the most important ones are those affecting key stages of their vital cycle, such as skipped reproduction, late sexual maturity, low fecundity, decrease of larval and juvenile survival rates, and a general increase of the natural mortality (Marshall et al., 1999; Lambert and Dutil, 2000; Morgan, 2004; Rideout and Rose, 2006; Skjæraasen et al., 2012). Altogether this leads populations to decrease their productivity and to increase their vulnerability to anthropogenic impacts, with fishing activities among the most important ones (Dutil and Lambert, 2000; Hiddink et al., 2011).

Another negative impact of bottom trawling on the benthic habitats is the loss of structural complexity, rugosity, and availability of holes and crevices, which are used by nekto-benthic small species and/or juvenile stages as shelter from predators. In bottoms with a low structural complexity, these species are more exposed, present higher mortalities and lower abundances (Choat and Ayling, 1987; Carr, 1989; Connell and Jones, 1991; Edgar and Shaw, 1995; Levin and Hay, 1996).

Although what has been stated so far represents a quite negative vision of bottom trawl fishing, it is a fact that this fishing activity supplies more than 50% of worldwide landings (Broadhurst et al., 2006), around 80 million tons per year, taking into account all fishing types together (FAO: http://www.fao.org/fishery/statistics). So, it does not seem realistic that bottom trawl fishing may be, in the short or medium term, substituted at a global scale by other fishing gears that could keep on supplying the current demand of sea food, while significantly reducing the negative impacts of bottom trawling. Nevertheless, there is the option of trying to optimize this fishing activity by improving its selectivity and reducing its impact on bottom communities, vulnerable and non-marketable species, and immature individuals. Ultimately, it is about trying to combine the sustainability of the bottom trawl fishery with the conservation of ecosystems and marine living resources.

In this sense, increasing the mesh size and/or changing its geometry in the codend are technical measures that have improved the selectivity of bottom trawl fishing and have reduced the discards and the catch of immature individuals or of those below the minimum landing size (e.g. Sardà et al., 1993; Petrakis and Stergiou, 1997; Ragonese et al., 2001; Bahamón et al., 2006; Guijarro and Massutí, 2006). The use of sorting grids in bottom trawl nets can also contribute to achieve this objective (Isaksen et al. 1992; Sardà et al., 2005, 2006; Massutí et al. 2009).

However, none of these measures can reduce the negative impact of bottom trawling on benthic communities. Most of the physical impact of the gears used is not caused by the codend but by dragging through the bottom the different elements that constitute the bottom trawl gear such as the metal doors, sweeps, chains and the net (Figure I).

The magnitude of the damage caused by bottom trawl gears to benthic communities depends largely on the biological traits and the resilience of the organisms present. Most of the available literature studying the effects of bottom trawling on biogenic habitats, particularly those mainly built up by slow growing and the most vulnerable organisms such as maërl beds, deep corals, or sponge bottoms, conclude that this fishing activity causes severe damages, which are recovered only on long term or can even be irreversible (e.g. Fossa et al., 2002; Barbera et al., 2003; Kaiser et al., 2006; Hogg et al., 2010). On the other side, most studies, basically experimental ones, conclude that the bottom trawl impact is relatively low and even ephemeral on sandy or muddy sedimentary bottoms (e.g. Sánchez et al., 2000; Kenchington et al., 2001; De Biasi, 2004; Kaiser et al., 2006). Nonetheless, other works studying the effects of bottom trawl fishing under commercial conditions conclude that the impacts on these type of bottoms can accumulate and involve profound changes of the

benthic communities (Smith et al., 2000, Hinz et al., 2009), and even, the modification of the bottom relief (Puig et al., 2012).

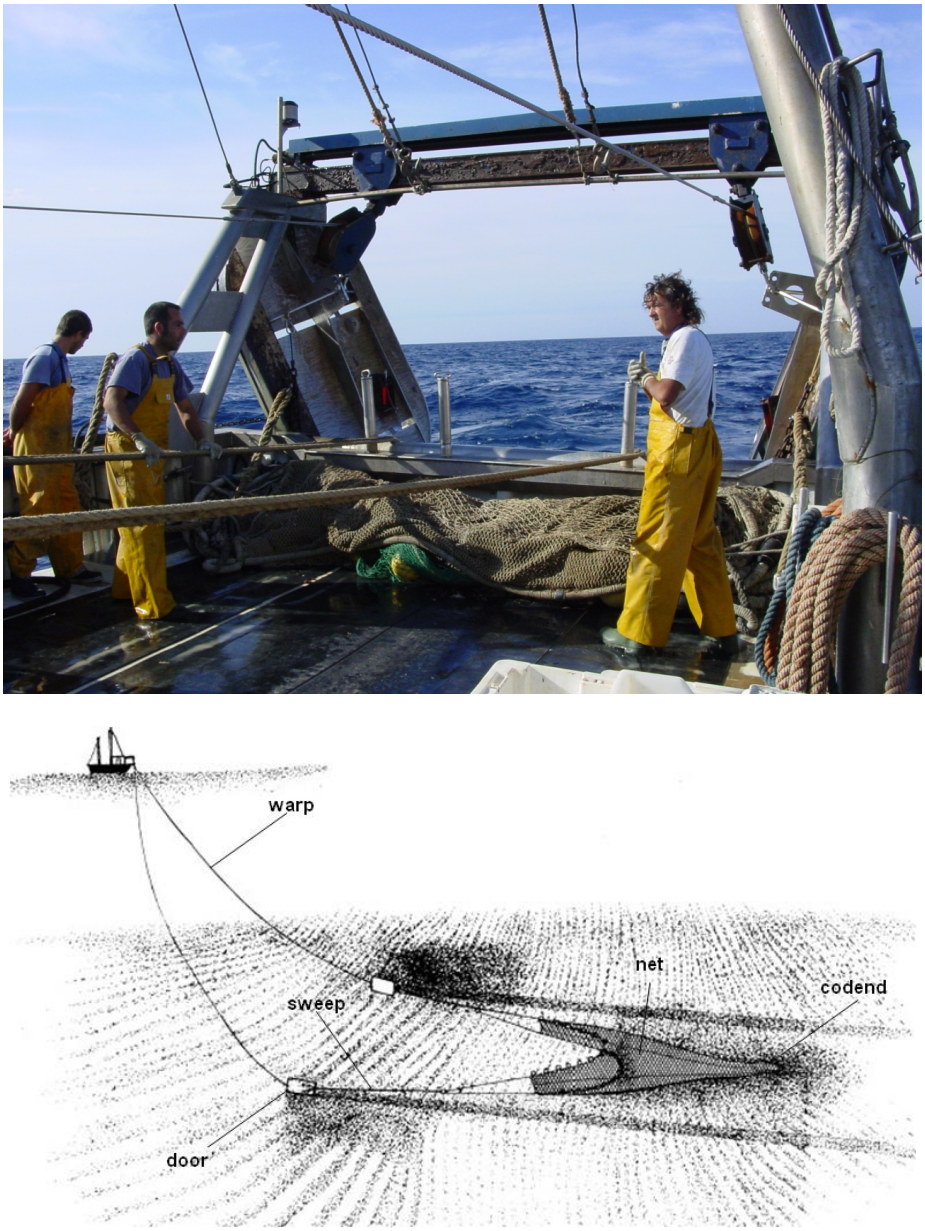


Figure I. Top picture: sailors at the manoeuvre to recover the bottom trawl gear on board a boat from the Balearic Islands. There can be seen a gear folded on the stern, the starboard door (hanging on the starboard side of the stern), and the sweeps (centre). Bottom drawing: scheme of a bottom trawl boat during a fishing operation. Adapted from www.gulfofmaine-census.org. Author: Joseph DeAlteris.

During the last decades, a shift in the assessment and management of fisheries is ongoing. Nowadays it not only takes into account the target species but also the whole ecosystem, even including economic, social and cultural aspects of fishing (Garcia et al., 2003; Pickitch et al., 2004; Browman i Stergiou, 2004; Coll et al., 2013). It is known as *Ecosystem Approach to Fisheries* (EAF), in comparison to the “traditional” approach, mainly mono-specific and based on

the state of the populations of exploited resources. In order to apply this assessment and management of fisheries, already incorporated to the European Union Common Fisheries Policy, it is essential to have a detailed knowledge on the relationships between exploited resources and the habitats where they grow and distribute.The effects of fishing on these resources, habitats and the rest of components of the ecosystem, and on their vulnerability and resilience should also be assessed.

Taking into account the important impact of bottom trawl fishing on ecosystems and exploited species, the application of the EAF must be a priority in order to allow achieving objectives such as 1) to reduce the impact on benthic habitats; 2) to guarantee the sustainability of the populations of target species, by reducing catches of individuals below the size at first maturity; and 3) to reduce the catch of vulnerable species and non-marketable ones.

To maintain habitats in a good state is essential for the development of the vital cycle of the species inhabiting them. According to the EAF, two types of habitats have been defined, the *Sensitive habitats* and the *Essential Fish Habitats*. In the case of the Mediterranean, the *Scientific, Technical and Economic Commitee for Fisheries* (STECF), of the European Commission, adopted the following definitions (STECF, 2006):

Sensitive Habitats: Fragile habitats that are recognized internationally as ecologically important and which support important assemblages of commercial and non commercial fish species and which may require a special protection (e.g. *Posidonia* meadows).

Essential Fish Habitats: Habitats identified as essential to the ecological and biological requirements for critical life history stages of exploited fish species, and which may require a special protection to improve stock status and long term sustainability.

The Balearic Islands bottom trawl fishery

The Mediterranean Sea is characterized by a great diversity of species and communities (Pérès and Picard, 1964; Fredj et al., 1992; Bianchi i Morri, 2000). Although it only represents 0.7% of global marine surface, it supplies a fishery production of around 900000 annual tons (Figure II), which represents more than 1% of the worldwide fisheries production.

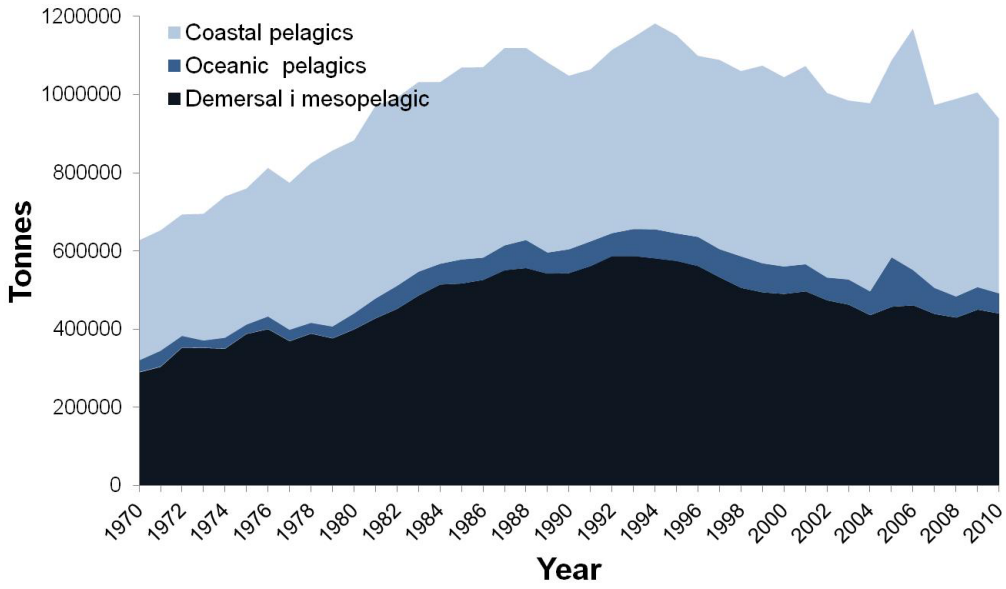


Figure II. Time series of Mediterranean fisheries landings. Source: FAO FishStat version 2.0.0.

Most Mediterranean catches consist of coastal pelagic fish, mainly sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), which represent around 55 to 60% of the landings (Figure II). The catches of demersal resources account for 40-45% of the total, and contrary to pelagic fish catches, they are markedly multi-species, with a great number of fish and invertebrate species, which are obtained using a great variety of fishing gears, among which bottom trawling stands out in terms of landings, fleet power, and fishing capacity (Lleonart and Maynou, 2003).

The Balearic Islands are not an exception to the multi-species character and the importance of the bottom trawl fishery in the landings of demersal resources. Moreover, the Islands can be a clear example of both. Although they present some characteristics that even differentiate them from the closer continental coasts in the western Mediterranean.

Compared to other areas, the bottom trawl fishing has a great relative importance in the Balearic Islands. Whereas in the closer coasts of the north west Iberian Peninsula the bottom trawl fishing represents up to 45-50% of the landings and a similar percentage is provided by the purse seine fleet, in the Islands the bottom trawl fishing produces up to 70% of the landings, followed by the artisanal fleet which contributes with up to around 20%, and finally, the

purse seine fleet contributes slightly above the 10% (Quetglas et al., 2012; Figura III).

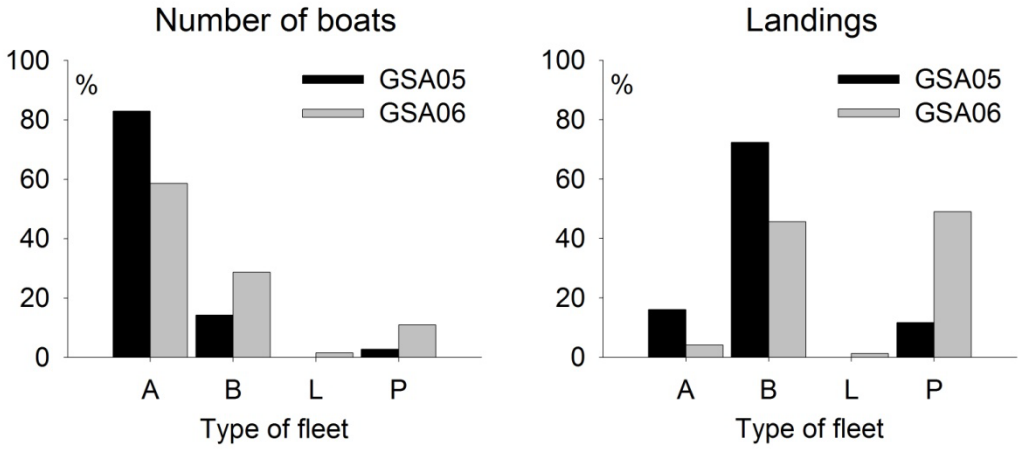


Figure III. Structure of the fishing fleet (% of boats per type of fleet to which they belong) and origin of the landings in the geographic sub-areas of the General Fisheries Commission for the Mediterranean GSA5 (Balearic Islands) and GSA6 (North east of the Iberian Peninsula). A: artisanal; B: bottom trawling; L: long liners; P: purse seiners. Adapted from Quetglas et al. (2012).

In this context, it is easy to understand that the fish trading structure in the Balearic Islands strongly depends on the catches supplied by the bottom trawl boats.

This fleet is almost entirely local in Mallorca and Menorca, where around thirty seven boats operate on both the continental shelf and the slope. In Eivissa and Formentera, the local fleet is composed of around seven boats that operate almost exclusively on the continental shelf, whereas the slope is exploited by an average of 20 boats coming from several harbours in the Iberian Peninsula (Quetglas et al., 2012; Figure IV), which are managed under the rules of an specific management plan (*ORDEN APA/1728/2005, de 3 de junio, por la que se regula la actividad de los buques de arrastre peninsulares que faenan en aguas profundas de los caladeros de las islas de Ibiza y Formentera*).

Even taking into account these boats harboured in the Peninsula but operating in the Balearic Islands, the bottom trawl fleet in the Archipelago is much more reduced than in the closer areas of the Peninsula coast, and so is the fishing effort carried out by these boats (Figure V).

This fact positively influences the presence of the most vulnerable species and the population structure of some of the main target species in this fishery. Hence, elasmobranch fishes, considered highly vulnerable to the fishing impact (Stevens et al., 2000), show higher abundance, biomass and diversity in the Balearic Islands than in the Iberian Peninsula (Quetglas et al., 2012). Similarly, the population of hake (*Merluccius merluccius*), an over-exploited species in both the Islands and the Peninsula (GFCM, 2014), shows larger sizes and a

higher percentage of individuals larger than the size at first maturity in the Archipelago (Quetglas et al., 2012; Figure VI).

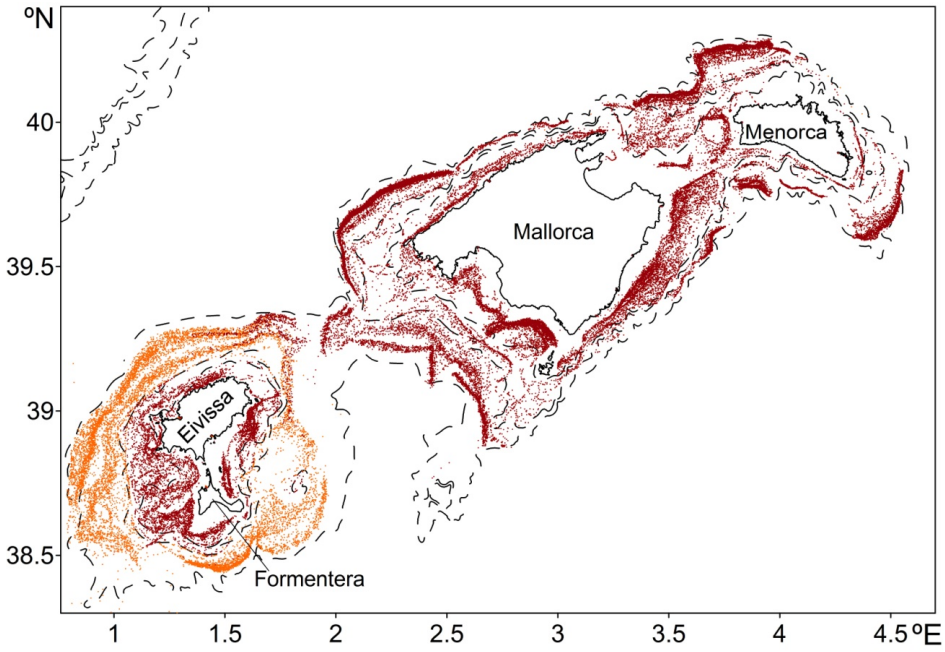


Figure IV. Map showing the signals of the *Vessel Monitoring Satellite System* (VMS) of the bottom trawl fleet around the Balearic Islands during 2011. Signals produced by the fleet with port base in the Balearic Islands are represented in red, those produced by the fleet operating in Eivissa and Formentera with port base in the Iberian Peninsula are represented in orange. Isobaths correspond to 100, 200and 800m.

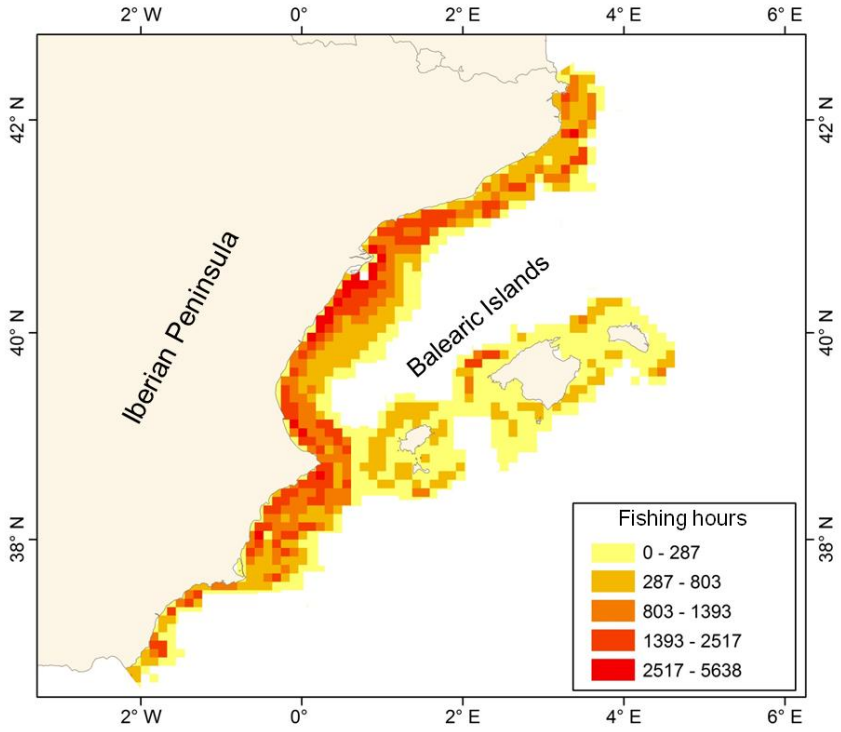


Figure V. Map showing the fishing effort carried out by the Spanish bottom trawl fleet during the period 2007-2010, calculated from the *Vessel Monitoring Satellite System* (VMS). Adapted from IEO (2012).

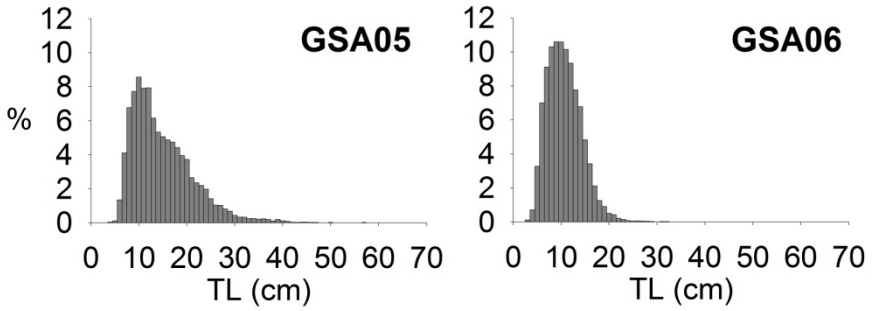


Figure VI. Length frequency distribution of the population of hake (*Merluccius merluccius*) in the Balearic Islands (GSA5) and in the north east of the Iberian Peninsula (GSA6), calculated from the data collected during the MEDITS research surveys. The size at first maturity for this species is 32.7 cm of total length (TL) (Oliver, 1993). Adapted from Quetglas et al. (2012).

Concerning the multi-species character of the bottom trawl fishery developed in the Balearic Islands, it is important to take into account the diversity of fishing strategies developed there by the bottom trawl fleet. From fifty meters of depth, the bottom trawl boats operate on both the continental shelf and the slope, where they can reach down to eight hundred meters of depth. In this bathymetric range four different basic fishing strategies have been identified, each one with different target species (Palmer et al., 2009). These strategies are quite coincident with the main communities of demersal species and resources described in the continental shelf and slope of the Mediterranean: e.g. Massutí and Reñones (2005) in the western basin, Biagi et al. (2002) and Colloca et al. (2003) in the central area, and Kallianiotis et al. (2000) in the eastern basin. A summary list of the bathymetric ranges and the main target species and/or commercial categories of these fishing strategies in the Balearic Islands, is stated below according to their landings, commercial value and economic yield (Figure VII):

- The shallow shelf, from 50 to 100 m depth, with the “morralla”, a mixed fish category in which a great variety of small and medium sized species (e.g. *Trigloporus lastoviza*, *Trachinus draco*, *Scorpena notata*, *Serranus hepatus*, *Serranus cabrilla, Chelidonichtys cuculus* and *Pagellus acarne*) and small individuals of larger species (e.g. *Scorpanea scrofa*, *Pagellus erythinus*) are gathered, the squid (*Loligo vulgaris*), the octopus (*Octopus vulgaris*), the striped red mullet (*Mullus surmuletus*) and the picarel (*Spicara smaris*), as main target species.

- The deep shelf, between 100 and 250 m depth, where the main target species are the hake (*M. Merluccius*) and the John Dory (*Zeus faber*).

- The upper slope, between 250 and 600 m depth, where the main target species is the Norway lobster (*Nephrops norvegicus*), but where the yields of hake (*M. merluccius*), megrim (*Lepidorhombus* spp.), monkfish (*Lophius* spp.), and blue whiting (*Micromesistius poutassou*) can also be important.

- The middle slope, between 600 and 800 m depth, where there is only one target species which is the red shrimp (*Aristeus antennatus*).

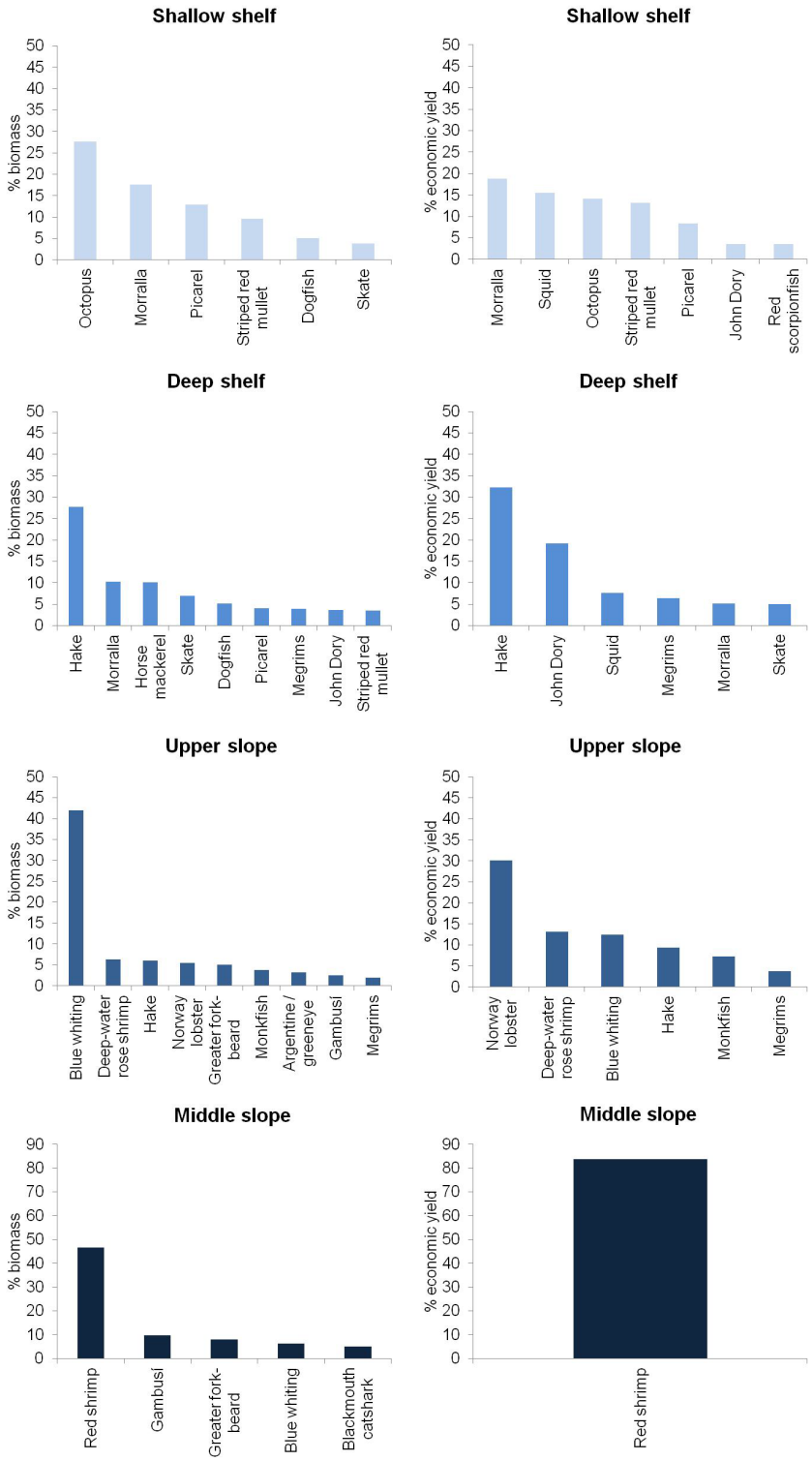


Figure VII. Main commercial categories by fishing strategy developed by the bottom trawl fleet of the Balearic Islands. In each strategy, the categories presented account for more than 75% in terms of biomass (left) and economic yield (right). Source: Daily sale bills per boat in the period 2007-2011, provided by the *Organització de Productors MallorcaMar* (Producers Organization in Mallorca). Shallow shelf: 50-100m; Deep shelf: 100-250m; Upper slope: 250-600m; Middle slope: 600-800m. Octopus: *Octopus vulgaris*, Morralla: different species of osteicthyans, Picarel: *Spicara smaris*, Striped red mullet: *Mullus surmuletus*, Dogfish: *Scyliorhinus canicula*, Skates: *Raja* spp., Squid: *Loligo* spp., John Dory: *Zeus faber*, Red scorpionfish: *Scorpaena scrofa*, Hake: *Merluccius merluccius*, Horse mackerel: *Trachurus* spp., Megrim: *Lepidorhombus* spp., Blue whiting: *Micromesistius poutassou*, Rose shrimp: *Parapennaeus longirostris*, Norway lobster: *Nephrops norvegicus*, Greater fork-beard: *Phycis blennoides*, Monkfish: *Lophius* spp., Argentine/greeneye: *Argentina* spp./*Chlorophthalmus agassizii*, Gambusí: *Plesionika* spp., Red shrimp: *Aristeus antennatus*, Blackmouth catshark: *Galeus melastomus*.

Whereas these fishing strategies or tactics are also present in other areas of the Peninsula coast, a particular trait that differentiates the Balearic Islands bottom trawl fleet is that its boats, in order to diversify their catches, frequently combine these basic fishing tactics during a daily fishing trip (Quetglas et al., 2012; Figura VIII).

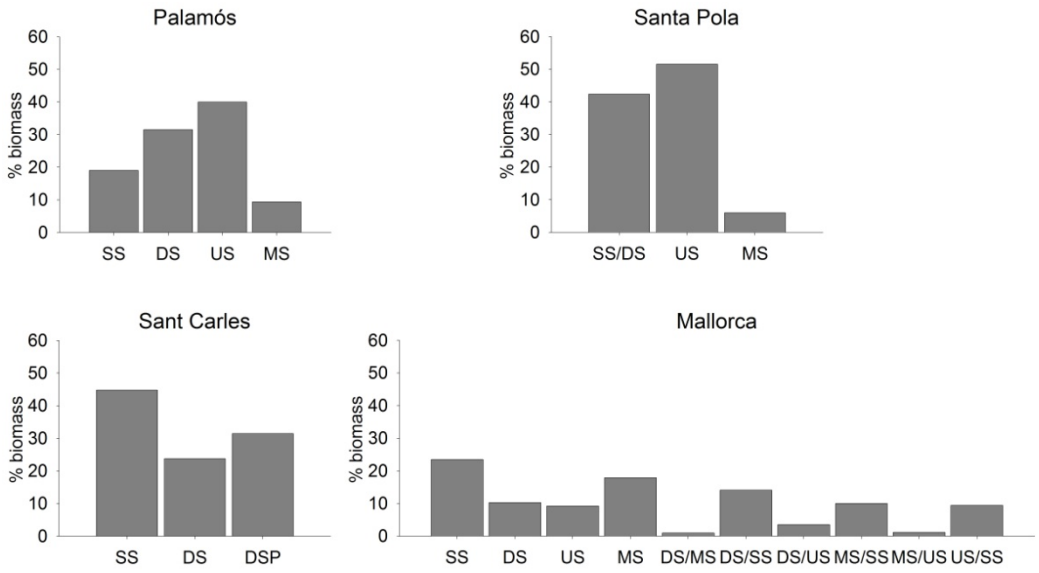


Figure VIII. Percentage of landed biomass by fishing strategy developed by the bottom trawl fleet of the Balearic Islands and from three of the most important harbours in the northeast of the Iberian Peninsula (Palamós, Santa Pola and Sant Carles de la Ràpita). SS: Shallow shelf; DS: Deep shelf; DSP: Deep shelf exploited using a semi-pelagic bottom trawl; US: Upper slope; MS: Middle slope. Adapted from Quetglas et al. (2012).

The fishing tactic to which the Balearic Islands' bottom trawl fleet dedicates more effort is that exclusively exploiting the middle slope, which represents an average of 40% of all reported fishing trips during the period 2000-2011. This strategy is also the one yielding the highest economic benefits (40% of the total), whereas the fishing strategy exclusively targeting the shallowest stratum, the shallow shelf, is the one landing the highest amount of biomass, an average of 21% of the total landed weight (Figure IX). Taking into account all fishing strategies exploiting the continental shelf, and deducting the commercial categories characterizing the slope in those days in which the fleet exploited both the slope and the shelf, an estimated 65% of the total landed biomass comes from the continental shelf. In terms of economic yields, this percentage is reduced to almost 40% of the total due to the higher economic value of the crustacean catches from the slope.

At the study area of the present PhD thesis, the Balearic promontory, the bottom trawl boats are present in ten ports: Pollença (one boat), Alcudia (3), Cala Rajada (4), Portocolom (1), Cala Figuera (4), Palma (5), Andratx (8), Sóller (4), Ciutadella (4) i Maó (3) (Figure X). Among all these ports, only Cala Figuera could be considered as a specialized one, given that their boats are almost entirely dedicated to exploit the continental shelf on bottoms shallower than 100 m depth (Figure X). Although in the other ports there are also boats mainly

dedicated to exploit only one stratum, in most cases the middle slope, and more frequently during summer due to the red shrimp reaches its highest market price, most boats choose to perform mixed fishing strategies, which represent one third of the fishing trips carried out by the bottom trawl fleet in Mallorca.

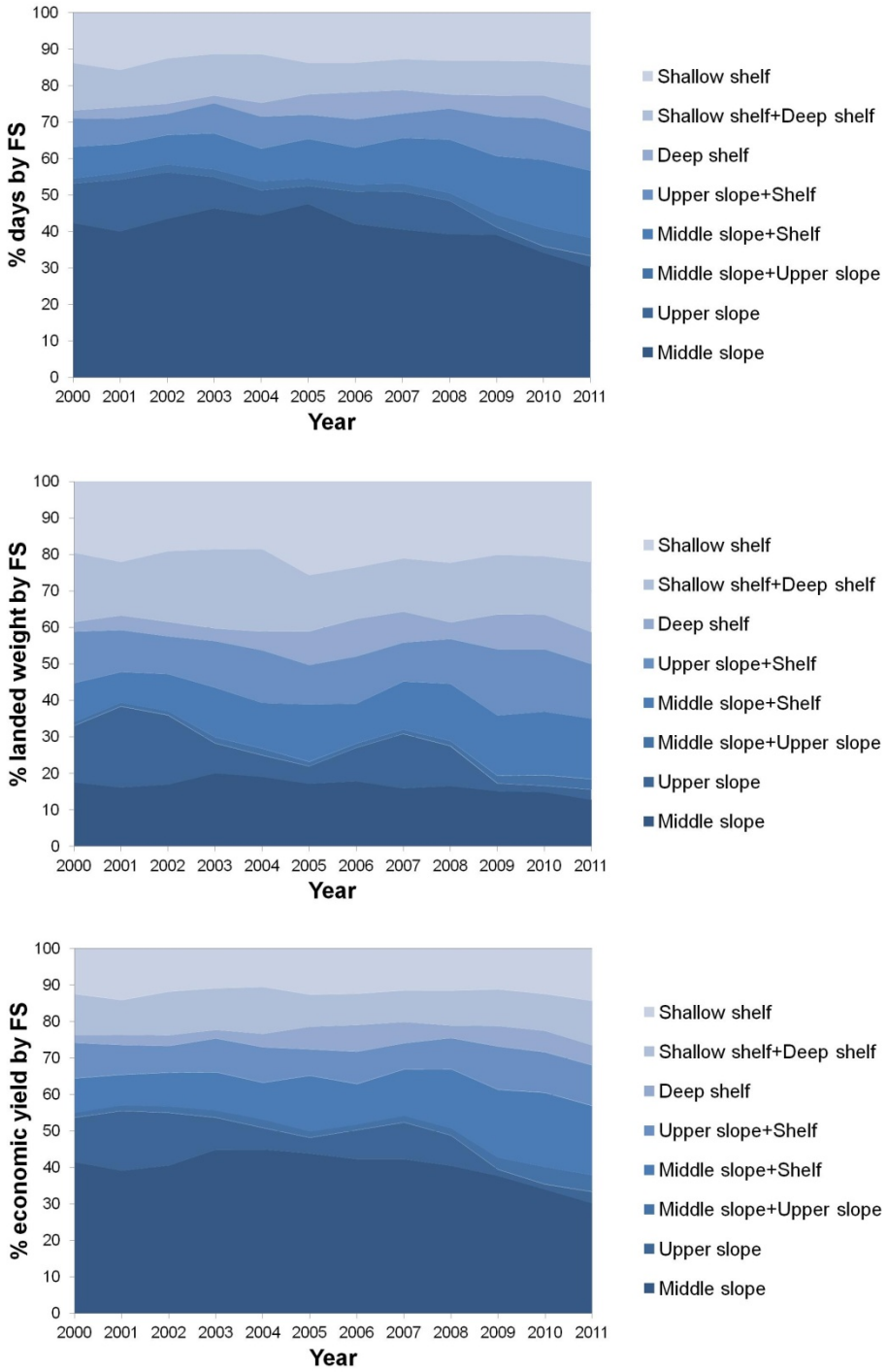


Figure IX. Percentage of days dedicated to each of the detected fishing strategies (FS), and their landed biomass and economic benefit during the period 2000-2011. Source: Source: Daily sale bills per boat in the period 2007-2011, provided by the *Organització de Productors MallorcaMar* (Producers Organization in Mallorca) and results of the analysis of fleet segments carried out in the frame of the *Data Collection Framework* funded by the EU.

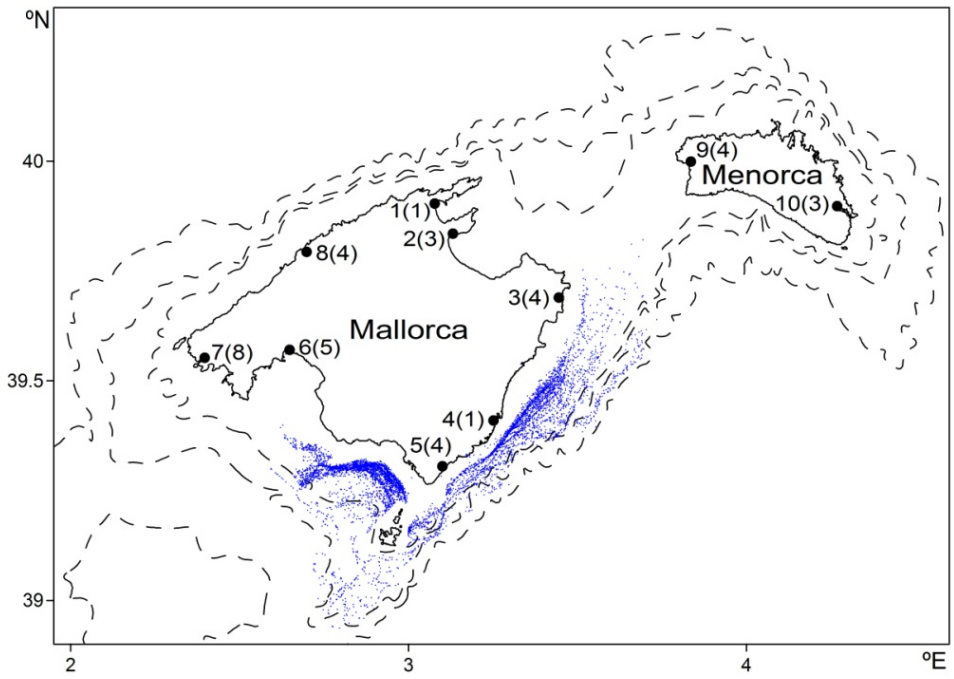


Figure X. Map showing the main ports in Mallorca and Menorca (1: Pollença, 2: Alcúdia, 3: Cala Rajada, 4: Portocolom, 5: Cala Figuera, 6: Palma, 7: Andratx, 8: Sóller, 9: Ciutadella, and 10: Maó) with the corresponding number of bottom trawl boats indicated between brackets. The Vessel Monitoring System (VMS) signals, produced during 2011 by the fleet harboured in Cala Figuera, are shown in blue. Isobaths correspond to 100, 200 and 800 m.

With the exception of the fishing strategy entirely dedicated to exploit the middle slope, which exclusively targets, and almost only catches, the red shrimp *A. antennatus*, the rest of fishing strategies are characterized by multi-species catches, with economic yields distributed among a larger number of species and/or commercial categories, the shallower are the exploited bottoms (Figure VII). The most pronounced case is the shallow shelf, where the most important commercial category in terms of economic yields, and second one in terms of landed biomass, is the “Morralla”, in which up to 60 by-catch osteichtyan fish species are gathered. None of these species is a target on its own, but altogether, they have become a target ‘species’ of the fishery (Figure VIII, Figure XI).

This variety of the catches from the fishing grounds of the continental shelf can be explained by the diversity of habitats found there, reported from the first studies on benthic communities of the Balearic Islands. In 1934, from the results of one of the first scientific surveys studying the continental shelf and shelf break off the Balearic Islands, Fernando de Buen reported the presence and importance of the facies of what he called “cascajo” in the shallow shelf, in which he described various types of red algae bottoms, and the crinoids (*Leptometra phalangium*) and brachiopod (*Gryphus vitreus*) beds in the deep shelf.

The oceanographic conditions of the waters surrounding the Balearic Islands are advantageous for the presence of these habitats. The absence of rivers in the Archipelago reduces the amount of terrigenous sediments.

Consequently, the presence of muddy bottoms is very scarce in the coastal shelf, where the bottoms with a biogenic origin predominate (Canals and Ballesteros, 1997). Most of the sediments of the continental shelf consist of sands and gravels with high percentages of carbonates (Acosta el al., 2002). The absence of rivers also reduces the supply of nutrients, which makes the waters of the Archipelago more oligotrophic than those in adjacent areas of the Peninsula coast and the Gulf of Lions (Estrada, 1996; Bosc et al., 2004). The absence of terrigenous sediments and the oligotrophy cause an increase of the water transparency, allowing light to reach deeper waters than in the mainland coast. Thus, the facies with red algae can develop in the shallow shelf down to 90 m depth (Ballesteros, 1992, 1994; Barberà et al., 2012). On the other hand, the channels between the Islands and between the Archipelago and the Iberian Peninsula, which characterize the hydrodynamics in the western Mediterranean due to their importance in the exchange of waters between the Balearic sub-basin, at the north of the Archipelago, and the Algerian sub-basin at the south, could positively influence the presence of some types of bottoms. This could be the case of the brachiopod and the crinoids beds, frequently related to areas of the deep shelf and shelf break affected by strong currents (Laborel et al., 1961; Emig, 1987; Pérès, 1985).

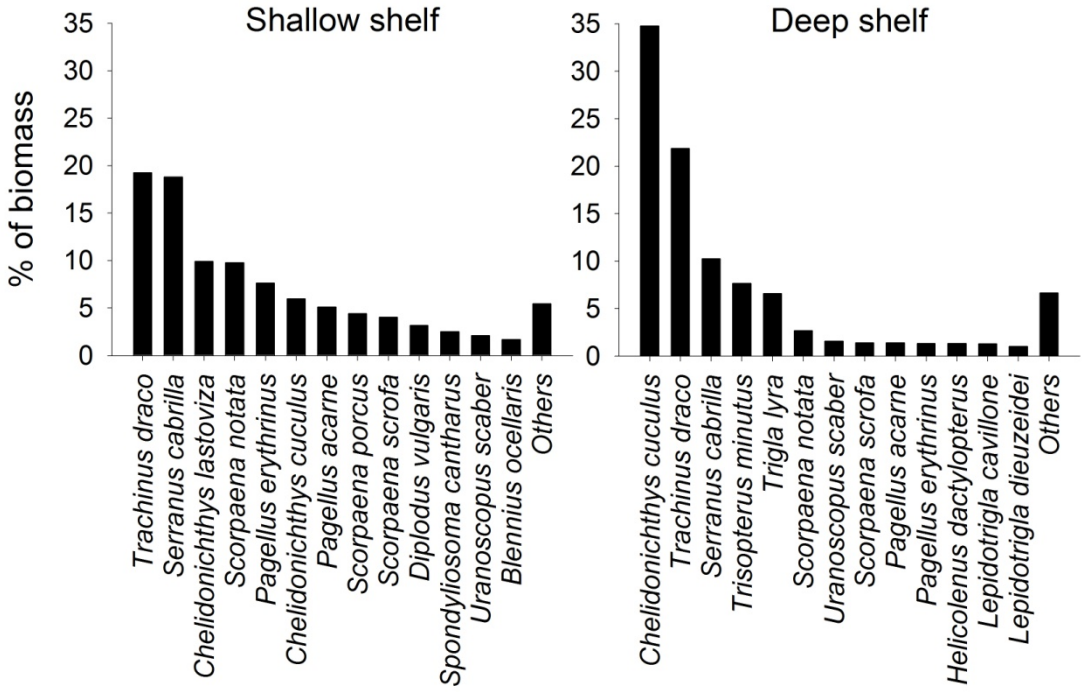


Figure XI. Composition of the landings of the 'Morralla' commercial category caught on the shallow (<100 m) and deep (100-250 m) shelf by the bottom trawl fleet of Mallorca. Average of the period 2008-2010. Source: Data collected during periodical samplings carried out by observers on board, in the frame of the Programa Nacional de Datos Básicos Pesqueros.

The fishing grounds traditionally exploited by the bottom trawl fleet of the Balearic Islands are distributed on these habitats. Particularly in the case of the "cascajo", about which de Buen (1934) explained "*Dejando hacia tierra arenas*

limpias, de granos con grosor diverso, o praderas vegetales, al descender a niveles inmediatos nos encontramos en la bahía de Palma, en toda la costa Sudoeste y, en general, en las Baleares, con una formación extremadamente variada y muy rica en invertebrados, a la par de la escasez, rareza y, en ocasiones, falta de peces. Incluimos a la totalidad de esta formación con el nombre de cascajo...". Among these bottoms, Fernando de Buen described several variations such as the "*cascajo orgánico*" with dominance of calcareous red algae and known nowadays as maërl, the "*avellanó*" beds with dominance of red algae of the Peyssonneliaceae family, the "*herba col*" or the kelp *Laminaria rodriguezii* bottoms, and the "*herba crespa*" or "*herba torta"* bottoms, with dominance of the soft red algae *Osmundaria volubilis*.

These facies are widespread and also show a high coverage and biomass, which, in the case of the *Peyssonnelia* beds, can be even higher than those of littoral algae bottoms of the western Mediterranean (Ballesteros, 1994). As in other areas, the primary production of some of these bottoms could be important for the sustainability of the animal communities inhabiting them. This would be the case of *Phyllophora antarctica* bottoms of the Antarctica, where this algae, which has a very abundant relative in the red algae bottoms of the Balearic Islands, the *P. crispa* (Ballesteros, 1992), represents a food source for higher trophic levels during the winter, allowing them to confront the seasonality of resources in that area (Norkko et al., 2004).

Most of the periodically assessed stocks of fishing resources in the Mediterranean are exploited over their maximum sustainable yield (Vasilakopoulos et al., 2014). The Balearic Islands are not an exception to it, and the striped red mullet (*M. surmuletus*) and the hake (*M. merluccius*), the two target species of the continental shelf which are periodically assessed, show symptoms of overfishing (GFCM, 2014). Although the clear multi-species character of these fishery, there is not any information of the exploitation state of other continental shelf species. The rest of assessments are carried out for species of the slope, more specifically the red shrimp (*A. antennatus*) and the Norway lobster (*N. norvegicus*).

The Balearic Islands, located 40 and 90 miles from Eivissa-Formentera and Mallorca-Menorca to the Iberian Peninsula, respectively, are among the most isolated insular areas, in terms of distance to the continent, in the western Mediterranean. An isolation which is also clear in terms of depth, since the Archipelago is separated from the Peninsula coast by depths reaching down to 2000 m, with the exception of the Eivissa channel where a depth of 800 m is reached (Figure XII). These distances and depths may certainly be effective barriers between the demersal ecosystems of the Balearic Islands and those of the Iberian Peninsula, at least for adult individuals of nekto-benthic species inhabiting the continental shelf.

This isolation of the Balearic Islands could represent an advantage for the conservation of demersal resources and ecosystems. Except for the bottom trawl boats harboured in the Iberian Peninsula that exploit the fishing grounds of the slope of Eivissa and Formentera (García-Rodríguez and Esteban, 1999), and some other boats that fish temporarily in Mallorca and Menorca using fishing traps (García-Rodríguez et al., 2000), the fishing fleet exploiting the

insular ecosystems and resources is mainly local. This fleet is less developed than the fleet of the nearby harbours in the Iberian Peninsula, particularly in the case of the bottom trawling, and in terms of both number of boats and their size (Quetglas et al., 2012). Consequently, the fishing effort in the Balearic Islands is lower than that of the adjacent areas in the Peninsula. On the other hand, the isolation of the insular ecosystems and demersal resources could be a problem in front of an eventual collapse of fisheries, because the recovery of the populations, at least for the continental shelf, could not be supported by the input of larval pelagic phases supplied from more productive peninsular ecosystems. Although it has been suggested that during the years in which the Balearic Front, that flows along the north of the Archipelago, is reinforced by the blockade of the North Current in the Eivissa channel (Figure XIII), there could be a supply of individuals of demersal species, such as hake (*M. merluccius*), from the Peninsula coast to the Balearic Islands (Massutí et al., 2008), the scientific evidences are still scarce.

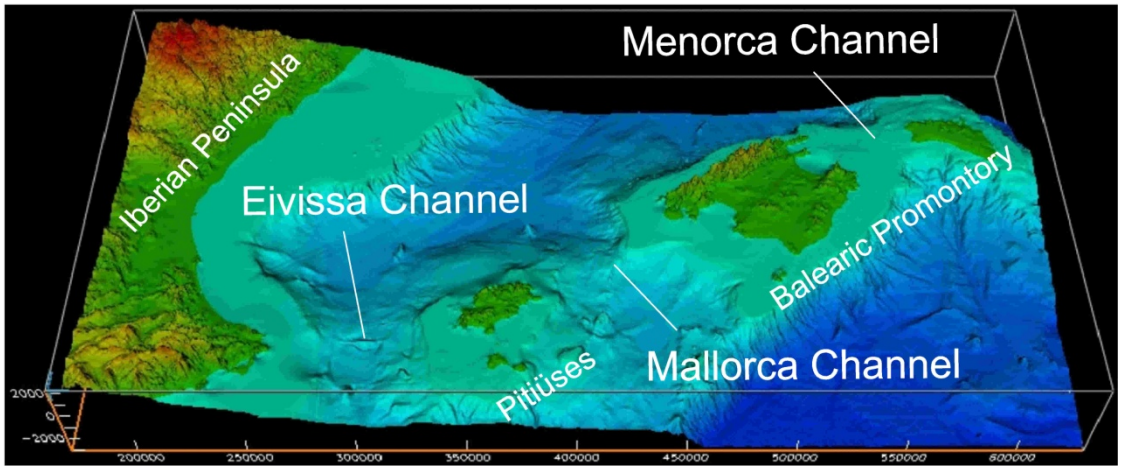


Figure XII. Bathymetric map of the Balearic Islands and the adjacent coast of the Iberian Peninsula. The channels of Eivissa and Mallorca, where the minimum depth reaches the middle slope at around 800 and 600 m, respectively, and the Menorca Channel, where the minimum depth is around 70 m, are also shown. Adapted from Acosta (2005).

The management measures applied to the bottom trawl fishery in the Balearic Islands, such as the time regulation of the activity (it is only allowed five days per week and fishing trips cannot last longer than 12 hours), the prohibition of fishing at depths shallower than 50 m, the minimum landing size in force for some species, and the recent change of mesh geometry in the codend, from diamond to square, are the same as in the Iberian Peninsula. The Balearic Islands is the region of Spain with the larger number of marine protected areas (up to eight; along with the Cabrera Archipelago Maritime-Terrestrial National Park, there are also the marine reserves of Palma Bay, the North of Menorca, the Straits of Eivissa and Formentera, the South of Mallorca, the Toro Island, the Malgrats Islands and the East of Mallorca), which are mainly located in littoral areas and do not affect the bottom trawl fishery. Only the Cabrera National Park and the reserve of the South of Mallorca include some traditional fishing grounds of the bottom trawl fleet, which in the case of Cabrera were

closed to this fishing activity when the park was created at the beginning of the 90's, whereas this type of fishing is still allowed, with some limitations, in the reserve of South Mallorca.

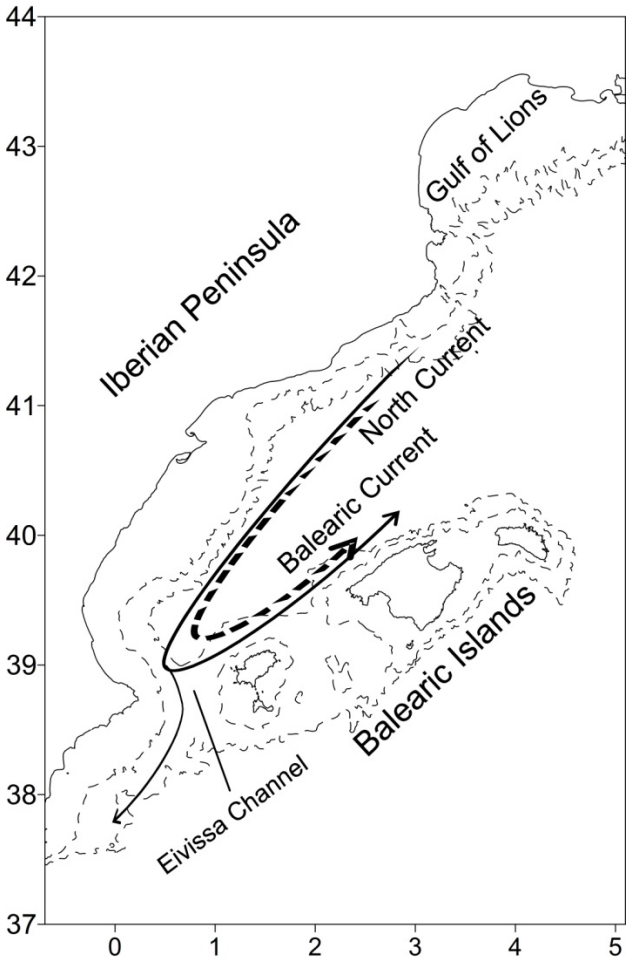


Figure XIII. Map showing the main slope currents at the northeast of the Iberian Peninsula and the Balearic Islands during spring-summer, after a mild (continuous line) and a cold (dashed line) winters. Isobaths correspond to 200 and 1000 m of depth. Adapted from Massutí et al. (2008).

Except for these marine protected areas, and some areas with submarine cables where the bottom trawling is forbidden, there is not any specific spatial management addressed to the protection of the benthic habitats in the rest of the bottoms potentially exploitable by the bottom trawl fleet of the Balearic Islands, even when some of these habitats have been recently protected by European and Spanish laws (coralligenous bottoms and maërl beds), that do not allow fishing on them using bottom trawl gears. The information needed to develop this kind of management, based on the cartography of the benthic communities and the activity of the bottom trawl fleet, is scarce (e.g. Menorca Channel; Barberà et al., 2012). Achieving this information, and disentangling the relationships between these communities and the associated organisms, are critical issues when trying to make compatible the sustainability of the bottom trawl fishery and the conservation of the marine environment and its living resources, one of the main current challenges for the management of the bottom trawl fishery of the Balearic Islands.

Aim of the thesis

This PhD thesis aims to improve the scientific knowledge on the benthic habitats and nekto-benthic communities exploited by the bottom trawl fishery in the circalittoral sedimentary bottoms of the continental shelf of the Balearic Islands. It analyzes with special interest the relationship between the benthic habitats and the nekto-benthic species inhabiting them and how the bottom trawl fishing activity affects the by-catch species of this fishery, of which, despite being typically multi-species, only the main target species are periodically assessed. It also evaluates a recently adopted technical measure aiming to improve the selectivity of this fishery. The results can contribute to implement an ecosystem approach to the assessment and management of the bottom trawl fishery of the Balearic Islands. The aims of the six scientific articles in which the PhD thesis is based on are set out below, along with the complete references to these publications:

Identify and describe the main benthic habitats (*Sensitive habitats* and *Essential Fish Habitats*) of the circalittoral sedimentary bottoms, exploited by the bottom trawl fishery of the continental shelf of the Balearic Islands, through the study of the macro-epibenthic organisms that characterize them, and to determine the relationships between these habitats and the distribution of the main nekto-benthic species.

Ordines F., Massutí E. (2009). Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 370-383. doi: 10.1002/aqc.969

To study the influence of the marine hydrodynamics on the distribution of benthic habitats in the east and south coastal shelf of Mallorca, and to assess whether it is a factor to be taken into account when defining the requirements and the use that nekto-benthic exploited species make of these habitats.

Ordines F., Jordà G., Quetglas A., Flexas M., Moranta J., Massutí E. (2011). Connections between hydrodynamics, benthic landscape, and associated fauna in the Balearic Islands, western Mediterranean. *Continental Shelf Research* 31: 1835-1844. doi: 10.1016/j.csr.2011.08.007

To characterize the role played by the main habitats detected in the coastal shelf of the Balearic Islands on the biology and physiology of characteristic nekto-benthic species of these bottoms, such as the red scorpionfish (*Scorpaena notata*), the comber (*Serranus cabrilla*) and the streaked gurnard (*Trigloporus lastoviza*).

Ordines F., Quetglas A., Massutí E., Moranta J. (2009). Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. *Estuarine, Coastal and Shelf Science* 85: 537-546. doi: 10.1016/j.ecss.2009.09.020

Ordines F., Bauzá M., Sbert M., Roca P., Gianotti M., Massutí E. (2014). Red algae beds increase the condition of nekto-benthic fish. *Journal of Sea Research* 95: 115-123. doi: 10.1016/j.seares.2014.08.002

To determine the main biological traits and to characterize the population dynamics of some of the species gathered together in the mixed fish

commercial category ‘Morralla’ (the comber *S. cabrilla*, the streaked gurnard *T. lastoviza*, the red gurnard *Aspitrigla cuculus* and the greater weaver *Trachinus draco*), one of the main by-catch categories of the continental shelf bottom trawl fishery of the Balearic Islands, and to assess the exploitation state of these species.

Ordines F., Farriols M.T., Lleonart J., Guijarro B., Quetglas A., Massutí E. (2014). Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean. *Mediterranean Marine Science*, 15: 613-625. doi: 10.12681/mms.812

To assess the effect of the change of mesh geometry (from diamond to square) in the codend of the bottom trawl nets, on the selectivity and yields of the bottom trawl fishery developed in the continental shelf of the Balearic Islands.

Ordines F., Massutí E., Guijarro B., Mas R (2006). Diamond *vs.* squared mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquatic Living Resources* 19: 329-338. doi: 10.1051/alr:2007003

Objectius

L'objectiu d'aquesta tesi doctoral és millorar el coneixement científic sobre els hàbitats bentònics i les comunitats necto-bentòniques explotades per la pesca de ròssec en els fons circalitorals sedimentaris de la plataforma continental de les Illes Balears. S'analitza amb especial interès la relació entre els hàbitats bentònics i les espècies necto-bentònics que els habiten i com n'afecta la pesca de ròssec les espècies by-catch d'aquesta pesquera, de la qual només se n'avaluen de forma periòdica l'estat d'explotació de les principals espècies objectiu, malgrat ser típicament multi-específica. Així mateix s'avalua una recentment implantada mesura tècnica per a millorar la selectivitat d'aquesta pesquera. La informació aportada pot contribuir a implantar una aproximació ecosistèmica en l'avaluació i gestió de la pesquera de ròssec de les Illes Balears. A continuació es detallen els objectius dels sis articles científics en que es basa la tesi i es mostren les referències completes d'aquestes publicacions:

Identificar i descriure els principals hàbitats bentònics (*Sensitive Habitats* i *Essential Fish Habitats*) dels fons circalitorals tous, explotats per la pesca de ròssec a la plataforma continental de les Illes Balears, mitjançant l'estudi dels organismes macro-epibentònics que els caracteritzen i estudiar les relacions entre aquests hàbitats i la distribució de les principals espècies necto-bentòniques.

Ordines F., Massutí E. (2009). Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 370-383. doi: 10.1002/aqc.969

Estudiar com influeix la hidrodinàmica marina en la distribució dels hàbitats bentònics en la plataforma costanera del Llevant i Migjorn de Mallorca i determinar si és un factor a tenir en compte a l'hora de definir els requeriments i l'ús que d'aquests hàbitats en fan les poblacions d'espècies necto-bentòniques explotades.

Ordines F., Jordà G., Quetglas A., Flexas M., Moranta J., Massutí E (2011). Connections between hydrodynamics, benthic landscape, and associated fauna in the Balearic Islands, western Mediterranean. *Continental Shelf Research* 31: 1835-1844. doi: 10.1016/j.csr.2011.08.007

Caracteritzar el paper que juguen els principals hàbitats detectats en la plataforma costanera de les Illes Balears en la biologia i fisiologia d'espècies necto-bentòniques característiques d'aquests fons, com són el cap-tinyós (*Scorpaena notata*), el serrà (*Serranus cabrilla*) i el rafel (*Trigloporus lastoviza*).

Ordines F., Quetglas A., Massutí E., Moranta J. (2009). Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. *Estuarine, Coastal and Shelf Science* 85: 537-546. doi: 10.1016/j.ecss.2009.09.020

Ordines F., Bauzá M., Sbert M., Roca P., Gianotti M., Massutí E. (2014). Red algae beds increase the condition of nekto-benthic fish. *Journal of Sea Research* 95: 115-123. doi: 10.1016/j.seares.2014.08.002

Determinar les principals característiques biològiques i caracteritzar la dinàmica poblacional d'algunes de les espècies que conformen la categoria comercial "Morralla" (el serrà *S. cabrilla*, els rafels *T. lastoviza* i *Aspitrigla cuculus* i la pinxa o aranya *Trachinus draco*), un dels principals *by-catch* de la pesquera de ròssec en la plataforma continental de les Illes Balears i avaluar-ne l'estat d'explotació d'aquestes espècies.

Ordines F., Farriols M.T., Lleonart J., Guijarro B., Quetglas A., Massutí E. (2014). Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean. *Mediterranean Marine Science*, 15: 613-625. doi: 10.12681/mms.812

Avaluar l'efecte del canvi en la geometria de la malla (de ròmbica a quadrada) dels cops de les xarxes de ròssec, en la selectivitat i els rendiments de la pesquera de ròssec que es desenvolupa en la plataforma continental de les Illes Balears.

Ordines F., Massutí E., Guijarro B., Mas R (2006). Diamond *vs.* squared mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquatic Living Resources* 19: 329-338. doi: 10.1051/alr:2007003

CHAPTER 1

Relationships between macro-epibenthic communities and fish on the continental shelf bottom trawl fishing grounds

Adapted from: **Ordines F.**, Massutí E. (2009). Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 370-383. doi: 10.1002/aqc.969

Abstract

The present study characterizes the macro-epibenthic assemblages and the relationships between demersal species and benthic habitats on the shelf trawl fishing grounds off the Balearic Islands (western Mediterranean). In these bottoms, three macro-epibenthic assemblages in both the shallow (at 38-91 m) and deep shelf (90-255 m) were identified. Macroalgae bathymetric distribution was identified as the main factor explaining the segregation between shallow and deep shelf assemblages. Two especially sensitive habitats were identified: the maërl and the crinoid beds; a third habitat was identified as the *Peyssonnelia* beds, which represented the highest biomass on the whole shelf, with similar species richness to the maërl beds. On the deep shelf, the crinoid beds were the bottoms showing the highest biomass. Habitat type had a significant effect on the distribution of demersal commercial species, most of them being more abundant in the two sensitive habitats mentioned and in the *Peyssonnelia* beds. Some species showed size specific habitat preferences. Fisheries management in the area should take into account the resilience of these benthic habitats, and their importance from both ecological and sustainable fisheries management perspectives.

Keywords: bottom trawl; shelf; macro-epibenthic communities; habitats; demersal species.

Relacions entre comunitats macro-epibentòniques i peix a la pesquera de ròssec de la plataforma continental

Resum

Aquest estudi caracteritza les associacions macro-epibentòniques i les relacions entre espècies demersals i hàbitats bentònics als fons de ròssec de la plataforma continental de les Illes Balears (Mediterrani occidental). En aquests fons s'hi identificaren tres associacions macro-epibentòniques tant a la part costanera (entre 38 i 91 m) com a la profunda (entre 90 i 255 m). El factor més important a l'hora d'explicar la segregació entre les agrupacions de la plataforma costanera i la profunda fou la distribució batimètrica de les macroalgues. S'han identificat dos hàbitats especialment sensibles: els fons de maërl i els de crinoïdeus; un tercer hàbitat, identificat com a fons de *Peyssonnelia*, presentà les biomasses més altes de tota la plataforma, i una riquesa específica semblant a la dels fons de maërl. A la plataforma profunda foren els fons de crinoïdeus els que presentaren les biomasses més elevades. Es detectà un efecte significatiu del tipus d'hàbitat sobre la distribució de les espècies demersals comercials, que en general foren més abundants als dos hàbitats sensibles detectats i als fons de *Peyssonnelia*. Algunes d'aquestes espècies mostraren preferències per un hábitat o un altre depenent de la talla dels individus. La gestió pesquera a l'àrea d'estudi hauria de tenir en compte la resiliència dels hàbitats bentònics, i la seva importància tant des del punt de vista ecològic com del seu paper en el desenvolupament d'una gestió pesquera sostenible.

Paraules clau: Ròssec; plataforma; comunitats macro-epibentòniques; habitats; spècies demersals.

1.1 Introduction

Fisheries science and management globally is progressively switching its attention from single species to ecosystems (Browman and Stergiou, 2004) including the Mediterranean, which is characterized by high diversity both at a community and species level (Pérès and Picard, 1964; Fredj et al., 1992; Bianchi and Morri, 2000). Numerous studies have contributed to the knowledge of population dynamics and biological parameters for the most important exploited species (see Moranta et al., 2008 for a review). In parallel, benthic communities have also been characterized, mainly in relation to bottom type, macroalgae and invertebrates (Pérès, 1985). During recent years, some studies have described the demersal assemblages (Moranta et al., 1998; Maynou and Cartes, 2000; Kallianiotis et al., 2000; Biagi et al., 2002; González and Sánchez, 2002; Madurell et al., 2004), but few of them have also explored their relation to benthic communities and habitats (Gaertner et al., 1999; Demestre et al., 2000; Colloca et al., 2003a), an aspect of great importance, both for the ecosystem approach to fisheries and for the understanding of some biological processes of exploited populations.

Sustaining the health of marine ecosystems and the fisheries they support requires avoiding degradation of ecosystems, taking into account the requirements of other ecosystem components (e.g. non-target species, protected species, habitat considerations and trophic interactions) and elucidating habitats critical to species for vital population processes (Pikitch et al., 2004). It has been shown that not only is there a correlation between macro-epibenthic communities and distribution of demersal species (Jackson and Harvey, 1992; Gaertner et al., 1999), but also an influence of habitat, among other factors, on the abundance, mortality and growth rate of their recruits (Connell and Jones, 1991). In the Mediterranean, García-Rubies and Macpherson (1994) demonstrated that some littoral fish species recruit to well-defined habitats, while Colloca et al. (2004) identified the shelf-break crinoid beds as a critical habitat for some demersal resources.

The existence of a relationship between benthic communities and demersal resources may be very important for the future management of fisheries, considering the increasing knowledge regarding the impact of fishing exploitation on marine ecosystems (Jennings and Kaiser, 1998; Gislason and Sinclair, 2000; Kaiser and de Groot, 2000). Trawling can not only cause damage to physical components of the habitats and a reduction in biodiversity, but also changes in the community structure and a decrease in the species abundance and size.

Besides the growing over-fishing observed during recent decades, fishing exploitation has also caused parallel destruction and degradation of the places that fish require to live. In fact, protecting essential habitats for fish and other important ecosystem components from destructive fishing practices increases fish diversity and abundance (Sainsbury et al., 1997; Roberts et al., 2001).

Thus, the conservation of ecosystems is required both from an ecological and fishing exploitation point of view, since the degradation of sensitive habitats and/or habitats essential to sustain fish populations has been of growing

concern during recent years (Auster and Langton, 1999; Pauly et al., 2002). The shelf around Mallorca and Menorca, two of the islands that comprise the Balearic Islands archipelago is narrow and steep on the northern side, and wider and gentler in the south, the shelf-break being located at an average depth of 140 m (Acosta et al., 2002). In contrast with the Iberian Peninsula, the absence of rivers in the archipelago reduces the amount of terrigenous and relatively mobile muddy sediments, most muddy bottoms being of biogenic origin (Canals and Ballesteros, 1997). The sediments of the Balearic shelf are mainly biogenic sands and gravels, with a high percentage of carbonates (Acosta et al., 2002). Within the general oligotrophic environment of the Mediterranean, the waters around the archipelago, where there is no supply of nutrients from land runoff, show more pronounced oligotrophy than the adjacent waters off the Iberian coast and the Gulf of Lions (Estrada, 1996). The hydrodynamic conditions around the Balearic Islands are characterized by high variability, as a consequence of circulation of the water masses through various channels between the islands (Pinot et al., 2002). The insular shelf could be considered as an isolated demersal exploited ecosystem, not only because of these geographical and environmental conditions but also from a fishing exploitation point of view. The Balearic Islands fishing fleet is mainly composed of small-scale and recreational boats, which use a great variety of gears, targeted at very different species (Lleonart et al., 1999; Goñi and Latrouite, 2005; La Mesa et al., 2005a; Morales-Nin et al., 2005); trawling intensity on the insular shelf and slope is much lower than along the peninsular bottoms. The bottom trawl fleet of the Balearic Islands is composed of about 40 vessels, on average 18 m in length and 55 GRT. The management of this fishery is based on effort control, with limitations placed on the number of boats, their nominal engine power (maximum of 500 hp) and the maximum time at sea (5 days per week and 12 h per day), and other technical measures such as prohibiting operation on bottoms shallower than 50 m, and in some marine protected areas and areas with submarine cables.

The environmental peculiarities of the Balearic Islands could be the reason for some of the differences observed when comparing the bottom trawl catches on the shelf of the Balearic Islands and those of the Iberian Peninsula. On the continental shelf of the Iberian Peninsula they are mainly composed of fish (Sánchez et al., 2004), whereas those on the insular shelf are characterized by large amounts of macroalgae and echinoderms (Carbonell et al., 1998). In the clear waters around the Balearic Islands, the algal beds develop down to 90–100 m depth (Ballesteros, 1992, 1994), forming the facies of soft red algae and calcareous red algae beds on the trawl fishing grounds (Massutí and Reñones, 2005).

Macroalgae meadows and their drifting accumulations have been demonstrated to play an important role in structuring soft-sediment communities on shallow shelf bottoms and increasing their biodiversity and productivity (Vetter, 1995; Steller et al., 2003; Norkko et al., 2004). The maërl (or rhodolith) beds are of great ecological importance. They have considerable value as nursery grounds for species of commercial interest and, at the same time, they are fragile and sensitive to fishing impacts (Donnan and Moore, 2003a, 2003b). These beds, which together with coastal seagrass meadows, coraligenous bottoms and crinoid beds are recognized as sensitive habitats of the

Mediterranean shelf (Ardizzone, 2006), have been recently protected by the European Council Regulation 1967/2006 for the management of the Mediterranean fisheries.

The study of habitats of special interest on the Mediterranean circalittoral soft bottoms has received little attention in contrast to other marine communities (e.g. coastal seagrass meadows). This is particularly evident in the Balearic Islands, where little is known about the shelf fishing grounds, in spite of their special characteristics and importance. The general aim of this paper is to evaluate the potential role of the benthic habitats, both from an ecological and fishery point of view. For these purposes, multivariate statistical techniques have been applied to data from experimental bottom trawl surveys, in order to identify the macro-epibenthic assemblages present on the shelf trawl fishing grounds, and to explore the relationships between main demersal species and benthic habitats.

1.2 Material and methods

1.2.1 Data source

The data used in the present work were collected during the BALAR surveys from 2002 to 2005. These surveys were conducted yearly, during late spring and early summer, on board the R/V Francisco de Paula Navarro (length: 30 m; engine power: 1100 hp; GRT: 178 t), and took place on the trawling fishing grounds along the continental shelf and upper slope off Mallorca and Menorca (Figure 1.1). Both sampling scheme and gear (GOC73) are the same as those generally used since 1994 throughout the Mediterranean Sea (Bertrand et al., 2002).

For the present analysis, data from 157 experimental trawls, between 38 and 255 m depth, have been used (Table 1.1). These hauls were conducted during daylight hours, with a duration of 20 min at <100m depth and 30 min at >100 m depth. The average towing speed was around 3 knots. The arrival and departure of the net to the bottom, in addition to the horizontal and vertical openings of the net (on average, 16.4 and 2.8 m, respectively), were measured using a SCANMAR system.

1.2.2 Data analysis

A matrix containing the data of macro-epibenthic species biomass in terms of kg/km^2 per haul was created. Species appearing in less than 5% of the samples were omitted. The data matrix was subjected to cluster analysis and non-metric multidimensional scaling (MDS), in order to characterize macro-epibenthic assemblages. Data were square-root transformed and the Bray–Curtis index was used as a between-haul similarity measure. Unweighted Pair-Group Method with Arithmetic Mean was applied to link samples into clusters. Similarity Percentage analysis (SIMPER) was used to assess species contribution to the detected communities. These techniques were carried out in PRIMER 5.2.8 package (Clarke and Warwick, 1994). Macro-epibenthic

assemblages were named according to previous works on benthic communities (Pérès, 1985; Ballesteros, 1994; Colloca et al., 2004). In order to simplify the analyses and their interpretation, data for shallow shelf and deep shelf were considered separately.

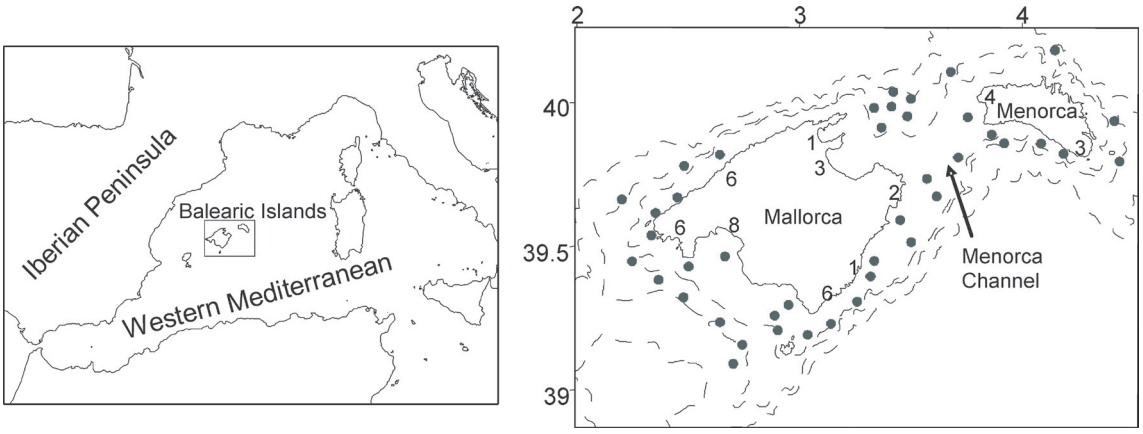


Figure 1.1. Map of the studied area off Mallorca and Menorca (Balearic Islands, north-western Mediterranean), showing, as examples, the experimental trawls carried out on the continental shelf during the 2005 BALAR survey. The number of trawlers in each port and 100, 200 and 800 m isobaths are displayed.

Table 1.1. Total number of hauls developed on the continental shelf during each bottom trawl survey, with their bathymetric range.

Survey	Date	Analysed hauls	
		Number	Depth (m)
BALAR0401	01/04/01-21/04/01	24	44-188
BALAR0502	01/05/02-25/05/02	39	39-219
BALAR0603	15/06/03-12/07/03	34	40-214
BALAR0404	20/04/04-18/05/04	42	38-255
BALAR0605	16/06/05-05/07/05	42	38-253

Species richness was calculated at a taxon level, by haul, including both macro-epibenthic and nekto-benthic species (algae were excluded because they were not identified to species level in most cases). Multivariate analysis of variance (MANOVA) was used to test for differences in the overall mean species richness between groups of hauls, corresponding to each macro-epibenthic assemblage. The SNK post-hoc test was applied to identify the differences detected. Only taxons for which more than two species appeared were included in this analysis. Before the application of parametric tests, data were checked for the assumptions of normality and homogeneity of variance.

Canonical analysis, available with the CANOCO 4.5 package (ter Braak and Smilauer, 2002), was used to model the distribution of the most important demersal resources species throughout the macro-epibenthic assemblages. The selection of species was based on their presence in the commercial landings (Guijarro and Massutí, 2006; Ordines et al., 2006), and demersal resources assemblages previously described in the area (Massutí and

Reñones, 2005). Those species appearing in less than 5% of the hauls were removed from the analysis. Pelagic or mesopelagic species not clearly related to benthic habitats (i.e. *Trachurus* spp., *Spicara smaris* and *Argentina sphyraena*), were also omitted. The species included in the analysis are listed in the Annex 1.1. Before the application of direct gradient (canonical) analyses, the length of gradient of the response variables, which were the square root transformed abundances (individuals/km^2) per haul of demersal resources species, was assessed by means of Detrended Correspondence Analysis. The resulting gradients were short (below 2.5 standard deviation units), and because the aim of the analysis was to study the absolute abundances, consequently a linear ordination method was used by applying Redundancy Analysis (RDA). The explanatory variables considered were depth and two nominal (categorical) variables: year, and macro-epibenthic assemblages. In RDA it is possible to specify covariables, which allows testing of the effect of a particular explanatory variable, after the variation explained by the covariables is factored out. The significance of the explanatory variables was assessed by means of the Monte Carlo permutation-based test (Manly, 1991). Before the design of the model, the interactions between explanatory variables were analysed and found to be non-significant. Details of the model and procedure are described in Table 1.2. The model was repeated by size classes (small, medium and large individuals), in order to investigate different patterns of distribution related with size. Hence, the abundance was calculated in each third of the length range, obtained for a particular species. In these last analyses, species with less than 200 individuals in total in all hauls, were omitted. Biplots corresponding to the RDA, where the explanatory variable was the macro-epibenthic assemblage, were created. In these diagrams, the perpendicular projections of symbols of macro-epibenthic assemblages onto the line overlaying the arrow of a particular species approximate its average abundance in that assemblage, and abundance is predicted to increase in the direction indicated by the arrow. The length of the arrows indicates how 'good' the model is in explaining particular species abundances (ter Braak and Smilauer, 2002).

The distribution of a set of species, which following the criteria of Pérès (1985) are indicators of circalittoral macroepibenthic communities in the western Mediterranean, as well as the total biomass and species richness including both macroepibenthic and nekto-benthic species, were modelled over the study area. Contour maps were done by applying the inverse squared distance gridding method, available on SURFER 8.0, on the biomass indexes (kg/km^2) and the number of species per haul, respectively.

Table 1.2. Description of the model used to test for each explanatory variable. In all cases the response variable was the abundance (individuals/km^2) of the main commercial species. In all cases 999 unrestricted permutations were done to test variable significance. MEBA: Macro-epibenthic species assemblages.

Test	Variable tested	Covariable
Effect of depth	Depth	Year, MEBA
Effect of sampling period	Year (category)	Depth, MEBA
Effect of MEBA	MEBA (category)	Depth, year

1.3 Results

1.3.1 Macro-epibenthic assemblages

In total, 151 macro-epibenthic species were identified. Cluster and MDS analyses showed the existence of six macroepibenthic assemblages (Figure 1.2). Three of those assemblages were located on the shallow shelf (SS) and were identified as *Peyssonnelia* beds (PB: 38-84m depth), maërl beds (MB: 54-74 m) and shallow shelf sandy-mud bottoms (SSM: 46-91 m). The other assemblages were located on the deep shelf (DS) and were identified as deep shelf sandy-mud bottoms 1 and 2 (DSM1: 90-255 m; and DSM2: 95-253 m, respectively) and crinoid beds (CB: 127-214 m). SIMPER results showed high biomass indexes for SS assemblages, which were dominated by echinoderms, algae, ascidians and sponges, whereas DS assemblages had lower biomass, and were dominated almost exclusively by echinoderms (Table 1.3).

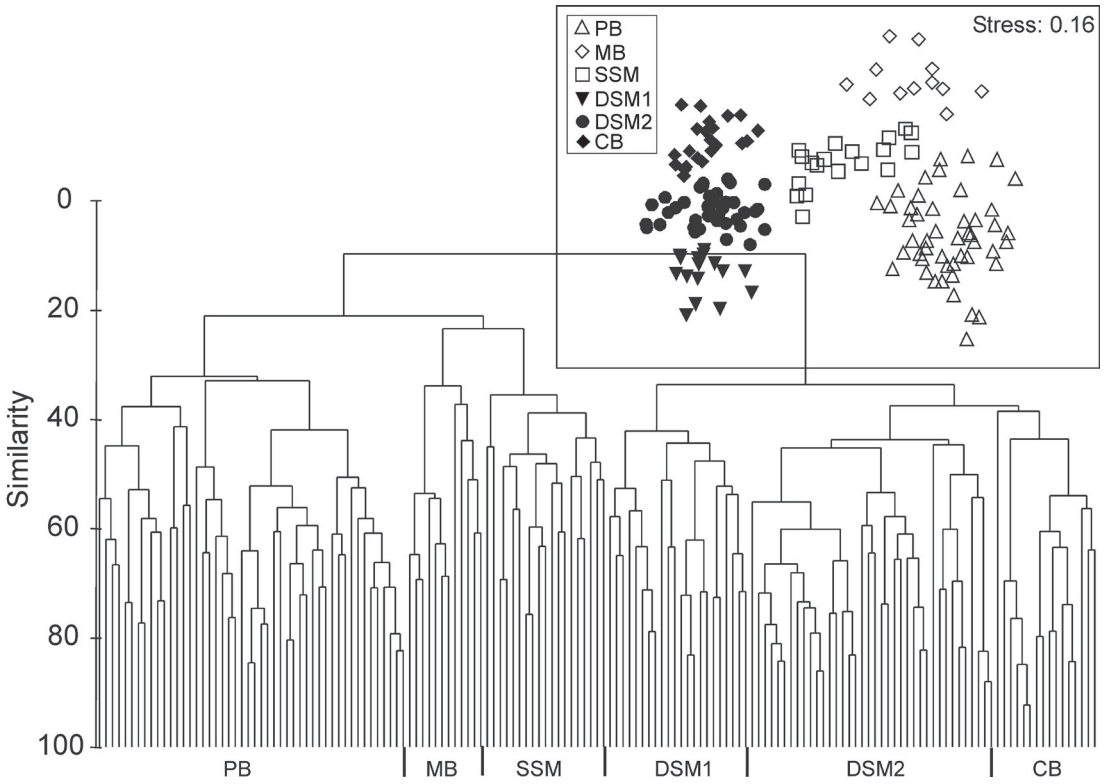


Figure 1.2. Cluster and MDS ordination of samples by their macro-epibenthic species composition in biomass (kg/km^2). PB: Peyssonnelia beds, MB: maërl beds, SSM: shallow shelf sandy-mud bottoms, DSM: deep shelf sandy-mud bottoms, CB: crinoid beds.

On the SS, PB showed the highest biomass indexes, being dominated by the echinoderms *Spatangus purpureus* and *Astropecten aranciacus*, the algae *Codium bursa*, *Phyllophora nervosa* and Corallinaceae, the ascidian *Ascidia mentula* and the sponge *Suberites domuncula*. Other important species within this group were the algae *Peyssonnelia* spp., which also showed high biomass indexes (2341 kg/km^2), and the echinoderms *Echinaster sepositus*, *Stichopus*

regalis and *Sphaerechinus granularis*, the ascidians *Phallusia mammillata*, *Microcosmus vulgaris* and *Diazona violacea*, and the crustacean *Dardanus arrosor*. MB showed lower biomass indexes, and was mainly dominated by Corallinaceae. Other important species within this group were *S. domuncula*, *A. mentula*, *D. arrosor* and *D. violacea*, the echinoderms *Luidia ciliaris*, *S. purpureus*, *A. aranciacus* and *E. sepositus*, and the large kelp *Laminaria rodriguezii*. SSM showed the lowest biomass indexes, especially for algal species. In this group the most abundant species were *C. bursa* and *S. regalis*. Other important species were *P. nervosa*, *S. domuncula*, the echinoderms *Cidaris cidaris*, *A. aranciacus* and *E. sepositus*, the ascidians *Aplidium conicum*, *A. mentula*, *M. vulgaris* and *D. violacea*, and the crustaceans *Pagurus prideauxi* and *D. arrosor*.

On the DS, DSM1 and DSM2 supported little biomass of macro-epibenthic species, DSM1 being dominated almost exclusively by *S. regalis*, and DSM2 by this same species and *Echinus* spp. Another important species was the echinoderm *Tethyaster subinermis*. CB had the highest biomass index in this depth stratum, and was dominated by the echinoderms *Echinus* spp., and *Leptometra phalangium*, with *S. regalis* and the brachiopod *Gryphus vitreus* also being abundant.

The contour maps of species which are indicators of circalittoral macro-epibenthic communities showed that Corallinaceae and *L. rodriguezii* predominate in the Menorca Channel, whereas *Peyssonnelia* spp. and *P. nervosa* predominate in south Menorca and south-west Mallorca (Figure 1.3). *L. phalangium* was mainly distributed in some areas in the south of Mallorca, the north of Menorca Channel and eastern Menorca.

1.3.2. Biomass and species richness

When both macro-epibenthic and demersal species caught in each haul were taken into account, the highest total biomass indexes were detected along the shallow shelf bottoms, and more specifically located off the south coasts of Mallorca and Menorca (Figure 1.4). The species richness per haul showed a similar plot (Figure 1.4). A total of 316 and 236 species were caught on the SS and DS, respectively.

Highly significant differences were detected when comparing the overall species richness at taxon level between macroepibenthic assemblages ($F_{22,130}$= 2.79, p< 0.001; $F_{16,136}$= 3.42, p< 0.001, for SS and DS respectively). On the SS, those differences were due to echinoderms and osteichthyans, which had a lower number of species in MB. On the DS, the differences were due to cnidarians, of which the greater number of species were found in DSM1, and to echinoderms and chondricthyans, of which a lower number of species occurred in DSM1 (Table 1.4).

Table 1.3. SIMPER results for each macro-epibenthic assemblage identified from cluster analysis and MDS of hauls. $\overline{Y}$: mean yields (kg/Km^2); $\overline{S_i}$: average similarity: SD: standard deviation; $\%\overline{S_i}$: percentage contribution to the similarity. Abbreviations are as in Figure 1.2.

PB $\overline{S_i}$ = 38.42	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Spatangus purpureus	4651.98	19.14	1.38	49.82	49.82
Codium bursa	690.70	3.93	0.67	10.23	60.04
Phyllophora nervosa	533.70	1.58	0.41	4.11	64.15
Corallinaceae	286.51	1.34	0.53	3.49	67.64
Astropecten aranciacus	21.23	1.22	0.78	3.18	70.82
Ascidia mentula	42.51	1.19	1.1	3.1	73.92
Suberites domuncula	18.78	1.14	1.16	2.97	76.89
Phallusia mammillata	56	1.01	0.58	2.64	79.52
Dardanus arrosor	7.52	0.76	1.09	1.98	81.5
Echinaster sepositus	7.44	0.73	1.54	1.91	83.41
Stichopus regalis	9.56	0.63	0.56	1.63	85.04
Peysonnelia spp	2340.57	0.57	0.15	1.48	86.52
Microcosmus vulgaris	9.29	0.52	0.75	1.35	87.88
Sphaerechinus granularis	44.15	0.48	0.42	1.25	89.13
Diazona violacea	25.90	0.47	0.33	1.22	90.35
MB $\overline{S_i}$ = 42.55	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Corallinaceae	1299.34	26.91	2.27	62.8	62.8
Suberites domuncula	51.64	3.30	0.95	7.70	70.5
Ascidia mentula	3.58	1.40	1.10	3.27	73.76
Dardanus arrosor	3.73	1.16	1.72	2.71	76.47
Luidia ciliaris	21.91	1.12	0.75	2.64	79.21
Diazona violacea	58.45	1.1	0.46	2.59	81.8
Spatangus purpureus	18.69	1.09	0.33	2.57	84.36
Laminaria rodriguezii	38.31	0.97	0.63	2.29	86.65
Astropecten aranciacus	9.74	0.92	0.51	2.16	88.82
Echinaster sepositus	0.47	0.66	1.39	1.54	90.36
SSM $\overline{S_i}$ = 42.43	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Codium bursa	61.88	8.63	1.79	20.67	20.67
Stichopus regalis	52.80	7.58	1.24	18.16	38.84
Ascidia mentula	10.85	3.93	2.16	9.41	48.25
Astropecten aranciacus	11.01	2.65	0.91	6.34	54.59
Microcosmus vulgaris	6.97	2.59	1.16	6.21	60.8
Cidaris cidaris	8.66	1.89	0.66	4.54	65.34
Dardanus arrosor	2.34	1.68	1.78	4.03	69.37
Phyllophora nervosa	24.71	1.67	0.6	4.01	73.38
Echinaster sepositus	1.78	1.6	1.78	3.83	77.21
Diazona violacea	35.58	1.58	0.52	3.8	81
Luidia ciliaris	3.31	1.37	0.82	3.28	84.29
Suberites domuncula	3.32	1.14	0.68	2.74	87.02
Osmundaria volubilis	5.7	0.64	0.38	1.52	88.55
Aplidium conicum	2.91	0.57	0.41	1.37	89.92
Pagurus prideauxi	3.62	0.57	0.56	1.37	91.29
DSM1 $\overline{S_i}$ = 47.25	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Stichopus regalis	46.18	38.89	4.23	82.31	82.31
Tethyaster subinermis	5.56	2.69	0.38	5.7	88.01
Echinus spp	4.09	1.74	0.39	3.68	91.69
DSM2 $\overline{S_i}$ = 49.99	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Echinus spp	49.86	23.29	2.95	46.59	46.59
Stichopus regalis	81.76	19.63	1.64	39.27	85.86
Tethyaster subinermis	6.96	2.25	0.46	4.49	90.36
CB $\overline{S_i}$ = 51.80	$\overline{Y}$	$\overline{S_i}$	$\overline{S_i}$/SD	$\%\overline{S_i}$	$\sum\overline{S_i}$ %
Echinus spp	358.86	21.54	1.84	41.59	41.59
Leptometra phalangium	259.28	15.25	1.28	29.45	71.04
Stichopus regalis	87.36	9.54	1.62	18.41	89.45
Gryphus vitreus	17.69	2.39	0.83	4.62	94.07

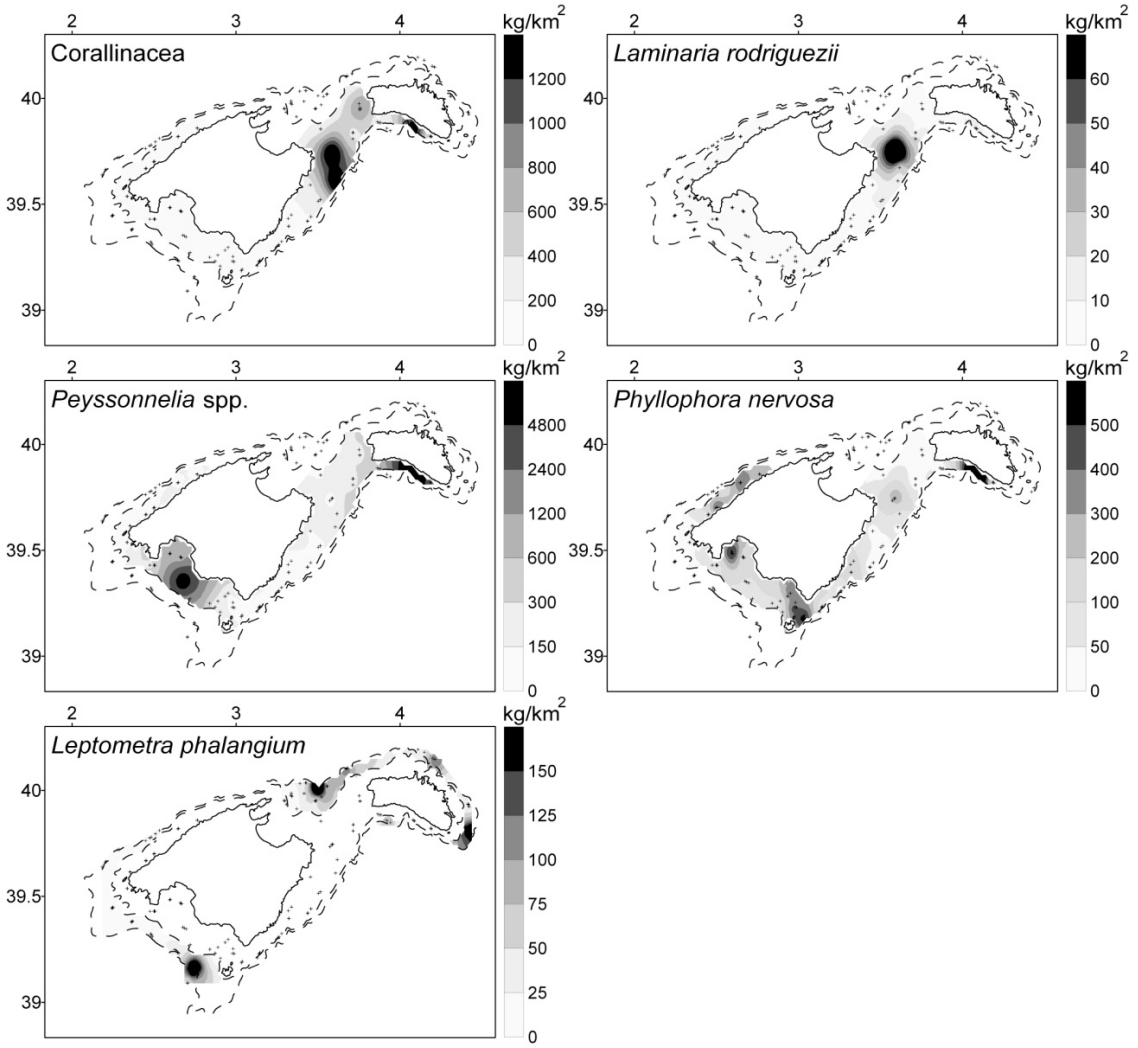


Figure 1.3. Contour maps of the most abundant macro-epibenthic species in maërl, *Peyssonnelia* and crinoid beds, which, following the criteria of Pérès (1985), are indicators of circalittoral macro-epibenthic communities.

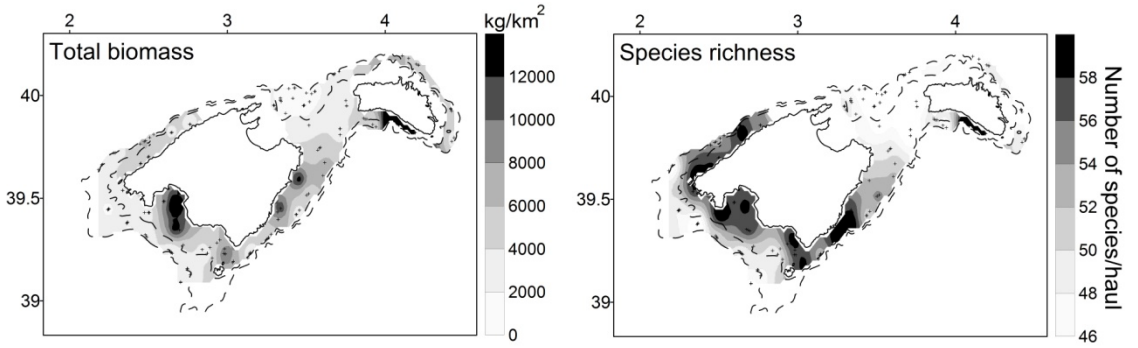


Figure 1.4. Contour maps of the most abundant macro-epibenthic species in maërl, *Peyssonnelia* and crinoid beds, which, following the criteria of Pérès (1985), are indicators of circalittoral macro-epibenthic communities.

Table 1.4. Mean species richness (± standard error) per haul for animal taxons appearing in each macro-epibenthic assemblage. The total number of species appeared by taxon taking into account all hauls, and SNK test results corresponding to the MANOVA analysis are also presented. Others are Briozoa, Annelida and Sipuncula for shallow shelf, and Briozoa and Annelida for deep shelf. N: number of species.

Shallow shelf					
Taxon	N	PB	MB	SSM	SNK
Porifera	27	3.4 ± 0.4	2.7 ± 0.6	3.2 ± 0.5	n.s
Cnidaria	13	0.8 ± 0.1	0.6 ± 0.2	0.8 ± 0.3	n.s
Mollusca	45	5.8 ± 0.3	5.2 ± 0.4	6.6 ± 0.5	n.s
Crustacea	27	3.8 ± 0.3	4.1 ± 0.7	2.5 ± 0.4	n.s
Echinodermata	31	7.7 ± 0.3	5.7 ± 0.7	7.6 ± 0.6	(PB=SSM)>MB
Brachiopoda	0	--	--	--	--
Ascidiacea	47	8.2 ± 1	7.3 ± 1.4	6.6 ± 1	n.s
Chondricthyes	17	3.4 ± 0.2	2.7 ± 0.6	2.8 ± 0.3	n.s
Osteichthyes	66	16.6 ± 0.7	10 ± 0.7	15.2 ± 0.8	(PB=SSM)>MB
Others	6	0.6 ± 0.2	1.2 ± 0.5	0.5 ± 0.2	
Deep shelf					
Taxon	N	DSM1	DSM2	CB	SNK
Porifera	16	0.7 ± 0.2	0.8 ± 0.2	0.4 ± 0.2	n.s
Cnidaria	11	1.4 ± 0.3	0.6 ± 0.2	0.3 ± 0.2	(CB=DSM2)<DSM1
Mollusca	34	6.2 ± 0.4	6.1 ± 0.3	7.1 ± 0.3	n.s
Crustacea	27	1.5 ± 0.2	2.0 ± 0.2	1.5 ± 0.3	n.s
Echinodermata	29	4.3 ± 0.3	5.1 ± 0.3	6.0 ± 0.4	(CB=DSM2)>DSM1
Brachiopoda	1	0.2 ± 0.1	0.5 ± 0.1	0.8 ± 0.1	
Ascidiacea	27	1.1 ± 0.3	0.8 ± 0.3	0.8 ± 0.4	n.s
Chondricthyes	13	2.8 ± 0.2	3.7 ± 0.2	3.6 ± 0.4	(CB=DSM2)>DSM1
Osteichthyes	63	19.7 ± 0.8	19.7 ± 0.8	19.8 ± 1.1	n.s
Others	3	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.2	

1.3.3 Macro-epibenthic assemblages and demersal resources

In total, 39 demersal resources species, 16 species for SS and 23 for DS, were used to evaluate the relationships between macroepibenthic assemblages and fish. On the SS, the results of the RDA showed that all the explanatory variables tested were significant and explained 33.6% of the total variance when the whole population of demersal resources was analysed. By size class, the explanatory variables were also significant and the variances explained ranged from 24.3 to 31.9%. On this depth stratum, the sampling period explained the highest percentages of variance for all classes, whereas macro-epibenthic assemblage turned out to be more important than depth for the whole population and for large size class individuals (Table 1.5).

On the DS, the RDA showed that the three explanatory variables in the model were significant for both the whole population and by size classes. The variables in the model explained 26% of the total variance when the whole population of the demersal resources was analysed. By size class, the variances explained by the model ranged from 21.4 to 25.3%. Depth was the most important variable in all cases, followed by macro-epibenthic assemblage for medium size class individuals (Table 1.5). At a species level, on the SS the RDA biplot for the whole population showed higher average abundances for: *Mullus surmuletus*, *Sepia officinalis*, *Chelidonichthys lastoviza*, *Blennius ocellaris*, *Scorpaena notata* and *Scorpaena scrofa* in PB; *Octopus vulgaris*,

Scyliorhinus canicula, *Serranus cabrilla*, *Scorpaena porcus*, and *Loligo vulgaris* and *Zeus faber* (these last two species with average abundances only slightly higher than in SSM) in MB; and *Alloteuthis media*, *Mullus barbatus, Pagellus erythrinus* and *Trachinus draco* in SSM (Figure 1.5).

Table 1.5. Results of the Redundancy analysis on the whole population and by size class abundances (individuals/km^2) of the principal demersal resources. It is also shown the total variance explained by the explanatory variables, and in brackets, the percentage of variance explained by each variable in the model. The levels of significance of each explanatory variable are also shown. **: p< 0.01 and *: p< 0.05. MEBA: macro-epibenthic assemblage.

Shallow shelf				
Population	Tested variable	Variance explained (%)	F-ratio	p
Total	Depth	9.2 (27.4)	9.86	**
	Year	13.4 (39.9)	4.77	**
	MEBA	11.0 (32.7)	5.87	**
Small size class	Depth	8.9 (36.6)	8.46	**
	Year	9.6 (39.5)	3.05	**
	MEBA	5.8 (23.9)	2.78	**
Medium size class	Depth	9.8 (30.7)	9.74	**
	Year	12.8 (40.1)	4.24	**
	MEBA	9.3 (29.2)	4.62	**
Large size class	Depth	3.6 (13.7)	3.92	**
	Year	13.2 (50.2)	4.75	**
	MEBA	9.5 (36.1)	5.13	**
Deep shelf				
Population	Tested variable	Variance explained (%)	F-ratio	p
Total	Depth	11.4 (43.8)	10.92	**
	Year	8.6 (33.1)	2.75	**
	MEBA	6.0 (23.1)	2.88	**
Small size class	Depth	9.3 (43.5)	8.53	**
	Year	7.2 (33.6)	2.21	**
	MEBA	4.9 (22.9)	2.24	*
Medium size class	Depth	12.3 (48.6)	11.85	**
	Year	6.1 (24.1)	1.97	*
	MEBA	6.9 (27.3)	3.32	**
Large size class	Depth	7.3 (33.8)	6.35	**
	Year	8.2 (38.0)	2.38	**
	MEBA	6.1 (28.2)	2.65	**

On the DS, the RDA biplot for the whole population showed higher average abundances for: *Peristedion cataphractum*, *A. media*, *Citharus linguatula*, *Cepola macrophtalma*, *Merluccius merluccius* and *Lepidotrigla cavillone* in DSM1; *Illex coindetti*, *T. draco*, *Trigla lyra*, *S. cabrilla* and *Lophius budegassa* in DSM2; and *Z. faber*, *Trisopterus minutus*, *S. canicula*, *M. barbatus*, *Macropipus tuberculatus*, *M. surmuletus*, *Aspitrigla cuculus*, *Lepidorhombus boscii*, *Scaeurgus unicirrhus*, *Eledone cirhosa*, *Raja naevus* and *Raja clavata* in CB (Figure 1.5).

RDA biplots by size class showed some changes in the distribution of demersal resources depending on size. On the SS, large individuals of *L. vulgaris*, *O. vulgaris* and *S. cabrilla* tended to be associated to MB. Small individuals of *C. lastoviza* and *T. draco* were more abundant on SSM, whereas

large ones were more abundant on PB. On the DS, large individuals of *E. cirrhosa*, *L. boscii* and *S. cabrilla* and small *T. minutus* were more abundant on CB, whereas large individuals of *T. lyra* were more abundant on DSM2.

Relationships between *P. erythrinus* and macro-epibenthic assemblages seemed to change by size class, however, the short length of the arrows for small and large individuals indicates that the abundance of this species was poorly explained by the model.

1.4 Discussion

The analysis of macro-epibenthic species revealed the existence of six communities, as two main groups on either the shallow (590 m depth) or deep (>90 m depth) shelf. These two main groups can be clearly associated with the presence of algae, down to 90–100 m on the Balearic shelf (Ballesteros, 1992, 1994), and the effect of light attenuation through the water column. Although light is considered the most important environmental factor with respect to the distribution of benthic organisms on the continental shelf (Martí et al., 2005; Ballesteros, 2006), sediment type and bottom currents may also exert a crucial role in the distribution of some of the most abundant benthic organisms detected such as red algae and echinoderms (Pérès and Picard, 1964; Pérès, 1985).

The macro-epibenthic assemblages on the shallow shelf sandy bottoms were characterized by the abundance of macroalgae and echinoderms. One of the assemblages found at this depth was identified as maërl beds. These bottoms are almost exclusively structured by the hard, long-living red algae Corallinaceae in the basal layer and the brown algae *Laminaria rodriguezii* in the erect stratum. Maërl beds are characterized by accumulations of living and dead rhodoliths, often being found in subdued light conditions, so their bathymetric limit depends primarily on the degree of light penetration (Barbera et al., 2003). In the northeastern Atlantic they occur from low in the intertidal to 30 m depth, while in the Mediterranean they are distributed deeper (up to 180 m depth in the eastern basin). Although little is known about the distribution and ecology of maërl beds in the western basin, they have been associated with areas of moderate currents and are restricted to depths below 25 m (Soto, 1990). Off the Iberian coast, they have been found at depths shallower than 60 m (Ballesteros, 1988), while in the Balearic Islands they extend down to 90 m depth (Canals and Ballesteros, 1997). In European waters, these beds suffer a variety of anthropogenic perturbations, including direct exploitation through extraction, fishing impacts and chemical pollution by organic matter and excess of nutrients (Barbera et al., 2003). Another assemblage found on the shallow shelf was recognized as the deep-water *Peyssonnelia* beds, which cover large areas of the Balearic shelf between 40 and 90 m depth (Ballesteros, 1994). They are mainly structured by the freeliving red algae *Peyssonnelia squamaria* in the basal layer (there is also Corallinaceae, but with lower biomass indexes) and the soft red algae *Phyllophora nervosa* in the erect stratum. The irregular sea urchin *Spatangus purpureus* is also very abundant in this sandy community. From Ballesteros (1992), these bottoms are mainly composed of fast growing

red algae species, which annually renew most of their biomass, but in some areas are also covered by long-living Corallinaceae (up to 50%; Ballesteros, 1994). These soft red algae bottoms represent a great amount of biomass, with average values much higher than those of maërl beds. However, despite differences in biomass and in species composition, both macroepibenthic assemblages showed similar values of mean species richness for the range of macro-epibenthic species, except for the echinoderms. These results are in agreement with those reported by Ballesteros (1994), who estimated that the algal diversity of *Peyssonnelia* beds on the Balearic shelf are similar to maërl beds on that shelf and off the Iberian Peninsula. The deepest assemblage detected on the shallow shelf, with a mean depth around 77 m, showed the lowest biomass index, especially for algal species. These bare sandy-mud bottoms could be considered as a transition habitat between those already described, where light incidence can still support the development of macroalgae, and the deep shelf in which vegetation disappears.

The macro-epibenthic assemblages on the deep shelf detritic sandy-mud bottoms were characterized by low biomass indexes. The three assemblages detected on this depth stratum, were basically differentiated by the abundance of echinoderms. The assemblage with the highest biomass index was identified as *Leptometra phalangium* crinoid beds, which in the Mediterranean have been associated with detritic bottoms with regular currents (Colloca et al., 2003a).

The distributions of the species indicators of the three identified macro-epibenthic communities are in agreement with the environmental conditions required for their development. The Menorca channel is affected by strong northerly winds and offshore currents (Pinot et al., 1995), and is therefore a favourable area for the development of the maërl beds. These conditions, which in the shelf break are reinforced by the Balearic Current that flows along the northern slope of the Islands (Pinot et al., 2002), could also facilitate the development of *L. phalangium* beds. In contrast, soft red algae species predominated on areas with hydrodynamically and geomorphologically favourable conditions for the accumulation of these less dense algae. On one hand, it could be considered the ‘island mass’ effect, which produces calm water conditions in the lee of the islands (Mann and Lazier, 1991), and also the fact that the southern coast of Mallorca is more affected by southerly winds, being a region of weakened currents more favourable to the accumulation of particles (Werner et al., 1993). On the other hand, the southern shelf of Mallorca and Menorca is characterized by a series of fairly continuous and complex bars, roughly parallel to the coastline (Acosta et al., 2002). These submarine terraces, jointly with the existence of sand waves in some places, could favour the concentration of algal populations and their patchy distribution in the depressions.

Besides environmental reasons, the fishing effort could also be argued as another factor in relation to the location of these habitats. From a fishing exploitation point of view, the ports of Menorca and the north and north-eastern coast of Mallorca have a low number of trawlers (Figure 1.1), in contrast to the southern Mallorca coast, with a more highly developed trawl fishery, both in number of boats and their size. In addition, the widely developed trammel net fishery, which targets the decapod crustacean *Palinurus elephas*, on the

Menorca channel and neighbouring areas between March and August (Goñi and Latrouite, 2005), also reduces the trawl fishing effort on these shelf grounds during that period. The impact of otter trawling on maërl and crinoid beds in the Mediterranean has been documented and shown to cause a reduction of richness, abundance and biomass of benthic species (Smith et al., 2000; Bordehore et al., 2003). Moreover, these last authors demonstrated that in intensively trawled areas, the longliving rhodolith species are replaced by *Peyssonnelia* species that are faster growing and more resilient to trawling impacts.

The application of multivariate techniques allowed exploration of the relationships between demersal resource species and macro-epibenthic assemblages, taking advantage of eliminating from the model the variability due to the sampling period and depth. The results indicate that depth, although highly significant, was of secondary importance in structuring the principal demersal resource species of the shallow shelf, after macro-epibenthic assemblage. However, on the deep shelf, where macro-epibenthic assemblages present lower biomass, depth is revealed as the principal factor structuring the demersal resources species, although habitat still appears as a highly significant factor. In general, these results confirm the importance of the habitat in structuring demersal resources assemblages, reported by previous studies in other areas of the Mediterranean (Demestre et al., 2000; Colloca et al., 2003a) and suggested for the current study area (Massutí and Reñones, 2005).

On the shallow shelf, maërl and *Peyssonnelia* beds appeared to influence the distribution of most demersal resources. Twelve out of the 16 demersal resources species considered showed their highest average abundances on these bottoms. The importance of maërl beds in the western Mediterranean on biodiversity and abundance of macro-faunal species have already been reported by Bordehore et al. (2003) who stated that 'Mediterranean maërl grounds are sites with a high diversity and also support a high macro-benthic secondary production, which may be important for species of commercial interest'. On the other hand, *Phyllophora* species and their accumulations have an important role in structuring soft sediment communities in northern latitudes, also increasing faunal diversity (Dhargalkar et al., 1988; Norkko et al., 2004). In the Black Sea, the Zernov's *Phyllophora* field, which had almost disappeared by the 1980s, was reported to have high faunal diversity, with a high number of associated invertebrate and fish species (Zaitsev, 1992). In addition, the importance of macroalgae detritus in fuelling higher trophic levels has also been hypothesized for marine coastal systems (Vetter and Dayton, 1998, 1999). Although drifting algal mats undergoing anaerobic degradation have a harmful effect on faunal communities (Norkko and Bonsdorff, 1996a, 1996b) and a negative effect of macroalgae cover on sedentary filtering species (Everett, 1994), high rates of benthic secondary production have been found associated with accumulations of drift algae (Vetter, 1995). The soft red algae bottoms from the Balearic Islands showed the highest benthic biomass and higher species richness for some taxons (mainly for fish) than in maërl beds. The periodical removal of soft red algae biomass produced by trawl fishing exploitation could prevent the negative effect of algal accumulations. Moreover, following the commercial routine, most trawlers carry out a single haul on the shallow shelf

and focus successive hauls on the deep shelf or the upper slope. It is during these last trawls, when catches of the first haul are sorted and discarding takes place. This procedure could transfer organic matter to deeper bottoms, contributing to their enrichment. In this sense, submarine canyons in the vicinity of populations of macroalgae receive extensive inputs of macrophyte detritus and will probably be organically enriched by that material (Vetter and Dayton, 1999).

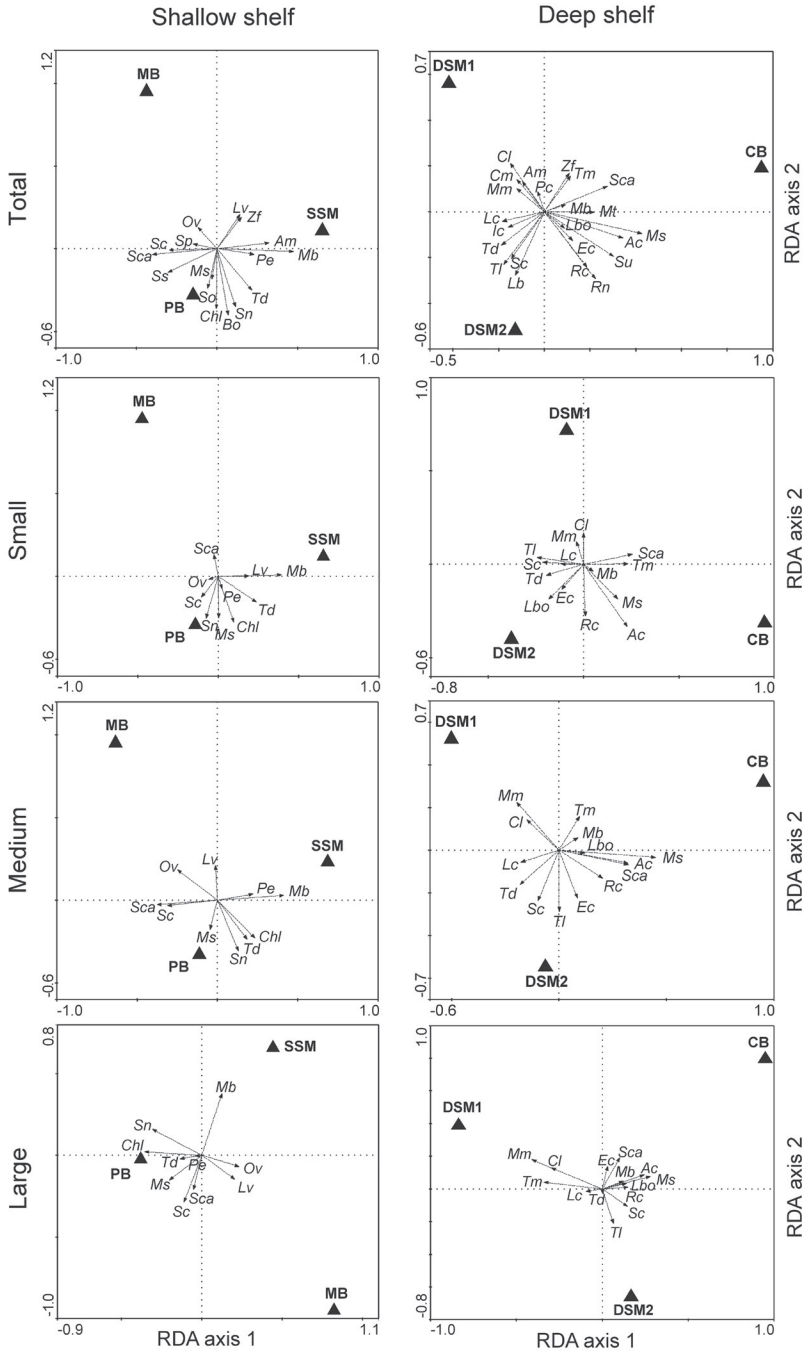


Figure 1.5. RDA biplots of macro-epibenthic assemblages and demersal resources for the whole population (Total), and for each size class (Small, Medium and Large), on shallow (left panel) and deep shelf (right panel). The full name of species and their taxonomic group are in the Annex 1.1.

On the deep shelf, the crinoid beds showed the highest average abundances for 12 out of the 23 demersal resources species considered. Similarly to soft red algae, the crinoid beds enhance habitat heterogeneity by developing three-dimensional communities (Gili and Coma, 1998). Colloca et al. (2004) considered these beds to be indicators of highly productive areas around the shelf break, sustaining large biomasses of benthopelagic fish and recruits and playing a major role in the production of commercially important species.

A few species, in both the shallow and deep shelf, showed different patterns of distribution across macro-epibenthic assemblages depending on their size. On the shallow shelf, small size classes of *Serranus cabrilla* were more abundant on *Peyssonnelia* beds, where they could find shelter from predators. This could also be the case of small-sized fish species such as *Scorpaena notata* and *Blennius ocellaris* which are found in higher abundances on these beds. Macrophytes are well known to provide both shelter from predators and food for fish species (Rozas and Odum, 1988). In the Mediterranean littoral, it has been observed that increased structural complexity by the macrophyte *Posidonia oceanica* meadows leads to increased densities of small species and/or individuals, which find more shelter and food there (Guidetti, 2000; Moranta et al., 2006). Soft red algae accumulations in northern latitudes have been reported to provide shelter from predators, and also small invertebrates living in algae and/or micro-organisms growing on the algae that can provide a valuable food resource for higher trophic levels (Norkko et al., 2000). Hence, the role played by *Peyssonnelia* beds could be analogous to that of *Posidonia oceanica* in coastal waters. The structural complexity is provided in the former bottoms by *Peyssonnelia* species, but more specifically, by the well developed erect stratum where soft red algae species like *Phyllophora nervosa* and *Osmundaria volubilis* predominate (Ballesteros, 1992, 1994). On the other hand, medium and large specimens of *S. cabrilla* and *Octopus vulgaris* seem to be more associated with maërl beds, where the rhodoliths could create more favourable conditions for its territorial behaviour (Macpherson, 1994) and for building their shelters or ‘dens’, respectively. The territorial behaviour of *S. cabrilla*, which depends upon individual size (García-Rubies and Zabala, 1990), could be on the basis of the habitat segregation between small and larger individuals. The latter ones could find more proper habitat features to define a territory in maërl, where bottom structures (i.e. rodoliths) are more stable, than in soft *Peyssonnelia* beds. In the case of *O. vulgaris*, the availability of material that can be utilized for ‘den’ construction has been reported to be a limiting factor in its distribution (Wodinsky, 1972; Katsanevakis and Verriopoulos, 2004). Moreover, these materials determine the abundance of breeding females in other *Octopus* species (Anderson, 1997). On maërl beds, rhodoliths could supply the materials necessary for ‘den’ construction, allowing the larger individuals to prepare for brooding. Other species that showed different patterns of distribution depending on size were *Chelidonichthys lastoviza* and *Trachinus draco*, which presented the larger individuals clearly associated to *Peyssonnelia* beds, whereas smaller ones were more abundant on sandy-mud bottoms. The preference for sandy-mud and algae-covered areas by *C. lastoviza*, which mainly feeds on epibenthic and infaunal invertebrates, has been reported (Labropoulou and Machias, 1998). *Trachinus draco* has been associated with sandy-mud bottoms where they usually remain buried (Bagge, 2004). The red

algal sediments on the Balearic shelf are mainly gravels or coarse sand (Fornos et al., 1988). Small individuals of fish species that display an active use of the sediment (e.g. scraping or burying) could prefer the sandy-mud bottoms, where the presence of red algae is almost negligible. On the deep shelf, small individuals of *Trisopterus minutus* were much more abundant on crinoid beds, whereas larger individuals tended to be located on bottoms with lower macro-epibenthic biomass. The opposite pattern was detected for *Eledone cirrhosa* and *Lepidorhombus boscii*. Colloca et al. (2004), in the central Mediterranean, found that several species of the deep shelf had a different pattern of distribution on *L. phalangium* beds, depending on the individual size. This was the case of Merluccius merluccius recruits which were more abundant on *L. phalangium* beds than on muddy bottoms. Results from the present study are similar for *L. boscii*, but contrary in the case of *M. merluccius*, whose abundances by size class always showed a negative correlation with crinoid beds off the Balearic Islands. The seasonality (in the central Mediterranean those differences were only detected in autumn) and the higher abundances of *L. phalangium* and high biomass indexes of other macroepibenthic species detected in the Balearic Islands could affect the favourable conditions detected for recruits in the former area.

The present study has shown that the distribution of demersal species is influenced by several macro-epibenthic assemblages, 'living bottom structures', which enhance habitat heterogeneity by developing three-dimensional communities. Two of them, the maërl and crinoid beds, considered to be sensitive habitats on the shallow and deep shelf, respectively (Ardizzone, 2006), are particularly vulnerable to towed gear (Barbera et al., 2003; Colloca et al., 2004). A third benthic habitat, the *Peyssonnelia* beds, is widespread and characteristic of the shallow shelf. This habitat, little known in the Mediterranean, should be less susceptible to bottom trawl and showed similar values of species richness, high biomass indexes (mostly attributable to algae and invertebrates), and higher abundance of demersal resources than maërl beds. In this sense, they could be considered as a critical habitat on the shallow shelf, because they appear to be indicators of highly productive areas and play a major role in the production of the main demersal resources.

In spite of their distinct resilience to trawling impact, the presence of these three benthic habitats on the Balearic shelf highlights the need to go towards multi-species and ecosystem-based assessment and management of trawl fisheries in the area. According to Jennings (2004), the broad purpose of the ecosystem approach to fisheries is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of society, without jeopardizing the options for future generations to benefit from the full range of goods and services (including fisheries and non-fisheries benefits) provided by marine ecosystems. However, the success of an ecosystem approach will depend on whether these high level and somewhat abstract commitments can be turned into specific, tractable and effective management actions (Sainsbury et al., 2000).

Thus, trawl fishery management on the Balearic shelf requires the development of technical measures to protect benthic communities, which could also benefit demersal resources populations by reducing the direct impact of

fishing mortality on crucial life stages (juveniles and spawners), and the indirect impact of fishing, represented by the loss of habitats that are necessary to complete their vital cycle. These measures could be based on spatial (and/or temporal) closures: (i) some areas already closed to trawling (e.g. submarine cable zones, marine protected areas including traditional trawl fishing grounds, agreement by fishermen to not operate with trawl on the shelf during summer) should be reinforced and/or extended; (ii) and other areas to be closed (at least temporally) should be considered. Also, to avoid the degradation of the ecosystems in areas that remain open to trawl fishing, these measures should be taken along with the development of ad hoc fishing managements for each particular habitat, in order to prevent levels of exploitation higher than the limits of resilience of the benthic communities involved.

Annex 1.1. Species abbreviations used in Figure 1.5, their scientific name and taxonomic group. C: Chondricthyes; CM: Cephalopod molluscs; DC: Decapod crustaceans; O: Osteichthyes.

Abbreviation	Scientific name	Taxonomic group
Am	*Alloteuthis media*	CM
Ac	*Aspitrigla cuculus*	O
Bo	*Blennius ocellaris*	O
Cl	*Citharus linguatula*	O
Cm	*Cepola macrophtalma*	O
Chl	*Chelidonichthys lastoviza*	O
Ec	*Eledone cirrosa*	CM
Ic	*Illex coindetti*	CM
Lb	*Lophius budegassa*	O
Lbo	*Lepidorhombus boscii*	O
Lc	*Lepidotrigla cavillone*	O
Lv	*Loligo vulgaris*	CM
Mm	*Merluccius merluccius*	O
Mb	*Mullus barbatus*	O
Ms	*Mullus surmuletus*	O
Mt	*Macropipus tuberculatus*	DC
Ov	*Octopus vulgaris*	CM
Pe	*Pagellus erithrynus*	O
Pc	*Peristedion cataphractum*	O
Rc	*Raja clavata*	C
Rn	*Raja naevus*	C
Sc	*Serranus cabrilla*	O
Sca	*Scyliorhinus canicula*	C
Sn	*Scorpaena notata*	O
So	*Sepia officinalis*	CM
Sp	*Scorpaena porcus*	O
Ss	*Scorpaena scrofa*	O
Su	*Scaeurgus unicirrhus*	CM
Td	*Trachinus draco*	O
Tl	*Trigla lyra*	O
Tm	*Trisopterus minutus*	O
Zf	*Zeus faber*	O

CHAPTER 2

Connections between hydrodynamics, benthic landscape, and associated fauna

Adapted from: **Ordines F.**, Jordà G., Quetglas A., Flexas M., Moranta J., Massutí E (2011). Connections between hydrodynamics, benthic landscape, and associated fauna in the Balearic Islands, western Mediterranean. *Continental Shelf Research* 31: 1835-1844. doi: 10.1016/j.csr.2011.08.007

Abstract

Linking the abiotic and biotic traits of ecosystems is a critical step towards understanding their structure and functioning. The east and south area of the Mallorca Island shows a high hydrodynamic variability on a medium spatial scale (tens of km). There is a gradient of mean water velocity ($\bar{U}$), with higher velocities at the northern part that slow down to the southern part of the Island. This hydrodynamic gradient has a significant influence on the distribution of macro-epibenthic species. It also influences the distribution of nekto-benthic fish species, which is also affected by the type of macro-epibenthic community that is present on the seabed. In this sense, fish size appeared to be a key attribute for the distribution of species across gradients of $\bar{U}$ and macro-epibenthic change. These findings can be applied in ecosystem-based fisheries management, as they show that it is necessary to take into account both the biotic and abiotic traits of the habitats when the habitat use and requirements of the associated species are defined.

Keywords: hydrodynamics; benthic landscape; associated species; habitat selection; essential fish habitats.

Connexions entre la hidrodinàmica, el paisatge bentònic i la fauna associada

Resum

Relacionar les característiques abiòtiques i biòtiques dels ecosistemes és una passa crítica a l'hora d'entendre la seva estructura i funcionament. A la zona del llevant i migjorn de Mallorca s'hi observa una variabilitat hidrodinàmica elevada a escales espacials mitjanes (desenes de km). Hi ha un gradient de velocitat mitjana de l'aigua ($\bar{U}$), amb velocitats més elevades a la part nord que tendeixen a ser més baixes a mesura que ens acostem al sud de l'Illa. Aquest gradient hidrodinàmic té una influència significativa sobre la distribució de les espècies macro-epibentòniques. També influeix sobre la distribució de les espècies de peixos necto-bentònics, la qual es veu afectada també pel tipus de comunitat macro-epibentònica que domina el fons. En aquest sentit, la mida dels peixos destaca com una característica clau a l'hora d'explicar la distribució d'espècies a través dels gradients de variació de $\bar{U}$ i de macro-epibentos. Aquestes troballes poden ser utilitzades per a l'aplicació d'una gestió pesquera basada en l'ecosistema, ja que demostren la necessitat de tenir en compte les característiques biòtiques i abiòtiques dels hàbitats a l'hora de definir tant els requeriments com l'ús que en fan d'ells les espècies associades.

Paraules clau: Hidrodinàmica; paisatge bentònic; espècies associades; selecció d'hàbitat; hàbitat essencial pels peixos.

2.1 Introduction

Determining the links between the abiotic and biotic traits is a critical step towards understanding the structure and functioning of ecosystems, and hence to developing ecosystem-based fisheries management (Pickitch et al., 2004). A recurrent issue is the influence of depth on the distribution of benthic and demersal organisms (i.e. Bianchi, 1991; Moranta et al., 1998; Kallianiotis et al., 2000; Massutí and Reñones, 2005). Depth is a readily measurable variable that brings together many other correlated factors (e.g. light, temperature, pressure, nutrient concentration) that can explain most of the bathymetric zonation of biota (Carney, 2005) because organisms tend to be located in depth strata in which their habitat requirements are met. These studies address the zonation of biota in large bathymetric ranges. However, when it comes to studying the distribution of communities within a particular depth stratum, the habitat characteristics that determine the horizontal distribution of organisms and their associations are not so well understood.

The flow variables, and particularly the current speed, have been reported to be key factors for benthic communities because they are major sources of disturbance due to their mechanical effects (e.g. erosion, sediment transport, redeposition) and because they determine the nature of the food supply to benthic organisms, and therefore the trophic structure of the communities (Warwick and Uncles, 1980; Warwick, 1984; Aller, 1989; Tenore et al., 2006). The role played by the hydrodynamics in shaping benthic communities has been reported for different environmental conditions: in coral reefs, where they determine the growth forms, abundance and diversity of coral species (Murray et al., 1977; Pichon, 1977; Jokiel, 1978); in the deep sea, where enhanced food availability caused by strong near-bottom currents has been linked to anomalous high abundances of benthic organisms (Thistle et al., 1985); and even in artificial reefs, where they determine the cover and diversity of sessile species (Baynes and Szmant, 1989).

The structural complexity of the bottoms and the type of benthic communities are probably the most used habitat characteristics to explain the horizontal variability of demersal fish communities in terms of habitat use and requirements. During the last decades, numerous studies have evidenced the earlier suggestion made by Petersen (1915) that ‘for each community on the level bottom exists one or more corresponding epifauna’ (i.e. Kaiser et al., 1999; Colloca et al., 2003a, 2004; Kaiser et al., 2004; Massutí and Reñones, 2005; Zimmerman, 2006; Ordines and Massutí, 2009). Moreover, it has also been reported that fish depends on the structural complexity and production of benthic habitats to carry out vital processes, such as recruitment, feeding, growth and reproduction (Choat and Ayling, 1987; Carr, 1989; Connell and Jones, 1991; Edgar and Shaw, 1995; Levin and Hay, 1996; Somarakis et al., 2004; Kamenos et al., 2004a; Ordines et al., 2009).

Recently, the importance of physical data other than depth (e.g. salinity, temperature and substrate) in structuring demersal fish communities has been highlighted (Katsanevakis et al., 2009; Ehrich et al., 2009; Juan-Jordá et al., 2009). However, with some exceptions (Ellis et al., 2000; Hinz et al., 2006), there are few studies of demersal fish that include both the abiotic and biotic

characteristics (e.g. benthic communities) of the habitat, and the interactions between these factors.

Two main benthic facies have been described for the circalittoral soft bottoms of the Mediterranean: the maërl and *Peyssonnelia* beds, characterized by red algae species of the Corallinaceae and Peyssonneliaceae families, respectively (Pérès, 1985). Maërl beds are considered to be sensitive habitats due to the high biodiversity they support and their low resilience (Donnan and Moore, 2003). *Peyssonnelia* beds support a high biomass and biodiversity (Ballesteros, 1994), and play an important role in the production of fish species, including some of the most important demersal resources of the coastal shelf (Ordines and Massutí, 2009). The bottoms of the coastal continental shelf off the Balearic Islands are characterized by the widespread presence of both maërl and *Peyssonnelia* beds (Ballesteros, 1994; Ordines and Massutí, 2009). In this area, at these depths (i.e. from 40 m to 90 m deep), the main source of temperature and salinity variability is the annual formation (in summer) and break down (in late autumn) of the seasonal thermocline. In terms of spatial variability, these variables appear to be fairly homogeneous around the islands (MedAtlas database: http://www.ifremer.fr/medar/). Although no specific studies have been conducted so far on the hydrodynamic spatial variability around the Islands, different sources of variability can be specified. First, there is the sheltering effect of the islands on the wind-induced circulation. The strongest winds in the region are from the N and NW (respectively named Tramontane and Mistral in the local terminology). Mallorca's Tramontane mountains are oriented perpendicular to the Tramontane/Mistral wind direction and therefore block the wind flow, resulting in calm seas on the lee side. Similar cases of islands blocking the wind have been observed in other parts of the Mediterranean Sea (Krotoni et al., 2001). Second, atmospherically forced island trapped waves, examined in a recent contribution by Jordi et al. (2009), could also explain part of the observed current variability. Finally, in different parts of the Mediterranean Sea different topographical features frequently combine to channel the wind flow between the islands and the islands and the mainland (Brody and Nestor, 1985). The channels between the Balearic Islands are important for the meridional exchange between waters from the northern basin and waters from the southern (Algerian) basin of the western Mediterranean (Pinot et al., 2002). These channels are associated with significant mesoscale variability (Pinot et al., 1994). In this scenario, the present work aims to determine the connections between the hydrodynamics, the benthic landscape, and the associated fish communities. To do so, a numerical model was used to determine the mean water velocity ($\bar{U}$) in the study area. Then, $\bar{U}$ was used to investigate 1) the role of hydrodynamics in shaping the macro-epibenthic landscape, and 2) whether the hydrodynamics is a factor to be taken into account when the habitat use and requirements of demersal fish communities are defined.

2.2 Material and methods

2.2.1 Hydrodynamic conditions

In situ observations of hydrodynamic parameters in our region (Figure 2.1) are unfortunately scarce and do not fully cover our region of interest. In order to establish the hydrodynamic characteristics of the area, the best choice was to use the realistic numerical model DieCAST (Dietrich, 1997), which provides a consistent dataset with good spatial and temporal coverage. DieCAST was used in the ESEOMED operational system (http://www.eseoo.org/servicios/oceano/ESEOMED.html) and is currently run operationally by the Spanish state agency Puertos del Estado. It provides daily hindcasts and forecasts of currents, temperature and salinity in the western Mediterranean. DieCAST is a 3D primitive equations model which uses a rigid lid approximation and the classical hydrostatic and Boussinesq approximations. It is coded in finite differences and uses z coordinates in the vertical. The main feature of DieCAST is that it is stable with low general dissipation and uses accurate control volume fourth-order numerics with reduced numerical dispersion. The horizontal resolution is 5 km, with a vertical resolution in the shallower areas ranging from 1 m to 5 m. The model implementation used here is similar to that developed by Fernández et al. (2005), to reproduce the climatological behaviour of the Mediterranean Sea system. In the present work we use the results obtained for 2007 and 2008.

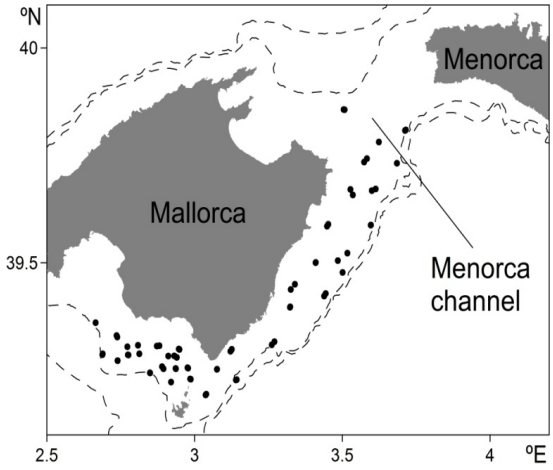


Figure 2.1. Map of the study area. Dots represent the sampling stations of the MIGJORN surveys. Dashed lines indicate 100 and 200 m isobaths.

In order to validate the model results, we used velocity observations obtained at Cape Enderrocat and Cabrera (see Figure 2 for location) by the TMOOS department of the Institut Mediterrani d'Estudis Avançats (IMEDEA, UIB-CSIC). Specifically, we used velocities measured at a depth of 10 m from November 2009 to January 2011 at Cape Enderrocat and from July 2009 to January 2011 at Cabrera. Unfortunately the observations and model results do not correspond to the same period, so a direct comparison of the two datasets was not possible. However, as we characterized the average conditions, we could compare the model and the observations from a climatological point of view. Namely, we compared the mean velocity and variance ellipses from observations and the model (Figure 2.2). Variance ellipses (Emery and Thomson, 1998) provide a graphical indication of the direction of maximum variability (shown by the tilt of the ellipse), the magnitude of that variability

(shown by the size of the ellipse) and the degree of anisotropy of the variability (shown by the ellipse eccentricity).

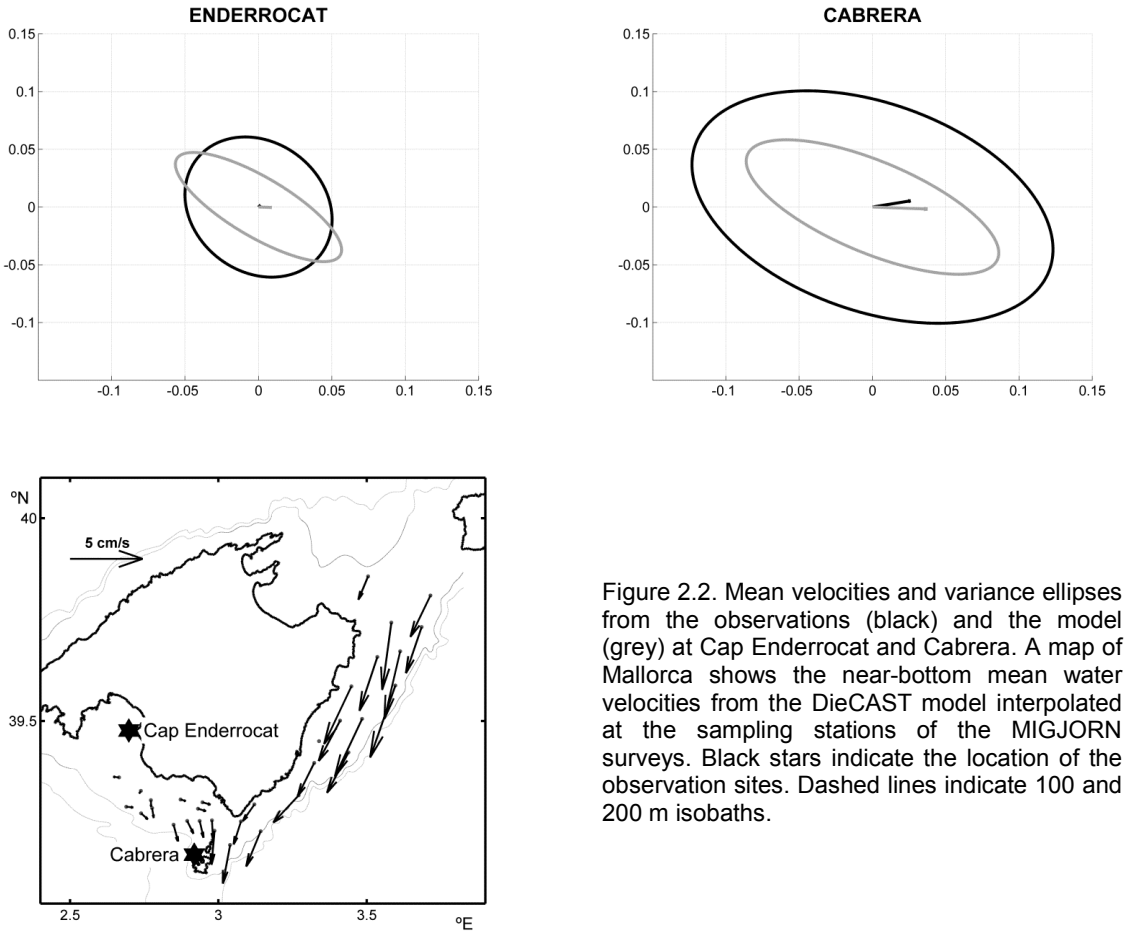


Figure 2.2. Mean velocities and variance ellipses from the observations (black) and the model (grey) at Cap Enderrocat and Cabrera. A map of Mallorca shows the near-bottom mean water velocities from the DieCAST model interpolated at the sampling stations of the MIGJORN surveys. Black stars indicate the location of the observation sites. Dashed lines indicate 100 and 200 m isobaths.

Mean velocities at Cape Enderrocat are very small according to both the observations (0.2 cm/s) and the model (0.7 cm/s). At Cabrera, both the observations and the model show an eastward mean current with a similar intensity (2.7 cm/s in observations; 3.4 cm/s in the model). In terms of flow variability, the magnitude and preferential direction obtained with the model are in good agreement with the observations at both sites. In both cases the preferential direction for the variability is NW-SE and the magnitude of the variability is larger at Cabrera than at Cape Enderrocat. The main difference between the model and the observations is that the flow variability in the model is slightly lower than in the observations, and that at Cape Enderrocat the model variability is more polarized. Nevertheless, from the comparison with the observations we can conclude that the model provides a reasonable estimate of the average conditions of circulation in the region.

In order to characterize the hydrodynamical conditions that affect the benthic communities we used the model velocities near the bottom. In particular, we calculated the mean water velocity ($\bar{U}$) as the temporal average over the whole simulation period of near-bottom velocities. An alternative could be to use the variance from the velocity time series, which would provide a

complementary view of the near-bottom dynamics. However, in our case, the spatial pattern of velocity variance is very similar to the spatial pattern of $\bar{U}$. Regions with stronger mean velocities are also the regions where current variability is strongest. Therefore, $\bar{U}$ is considered to be appropriate for characterizing the most energetic areas. Figure 2.2 shows a map of the distribution of $\bar{U}$ at the sampling stations. The eastern coast off Mallorca has a gradient of $\bar{U}$. The maximum mean values were in the Menorca channel and nearby areas (4.2 cm/s), and values gradually decreased along the eastern coast until minimum values were reached south of the island (0.4 cm/s). Although there have been no studies on the differences in $\bar{U}$ observed between the Menorca channel and the southeast Mallorca coastal shelf waters, the spatial pattern shown by the model can mainly be explained by wind forcing. As mentioned in the Introduction, the dominant winds in the area are from the N and NW. The Menorca channel (Figure 2.1) and the nearby area to the east of Mallorca Island is very exposed to these winds, setting up a wind-forced southwest circulation along Mallorca's south-eastern shelf. However, waters on the southern shelf of the island, located at the lee of the island, would be sheltered from such strong winds.

2.2.2 Sampling on board

The data used in the present work were collected in two bottom trawl surveys carried out during September-October in 2004 and 2005 on the coastal continental shelf off the southern and eastern coasts of Mallorca (Figure 2.1). The sampling gear was the GOC73, an experimental bottom trawl used since 1994 throughout the Mediterranean Sea (Bertrand et al., 2002) which has shown to be highly efficient in collecting both macro-epibenthic and nekto-benthicnekto-benthic species in the area (Ordines and Massutí, 2009). A total of 62 samples between 42 and 97 m depth were collected during daylight hours. The average towing speed was around 3 knots and the duration of the hauls was 20 minutes. The arrival and departure of the net to the bottom, in addition to its horizontal and vertical openings (on average 16.4 and 2.8 m, respectively) were measured using a SCANMAR system (www.scanmar.no), consisting in a set of sensors attached to the gear which allow its depth and geometry during the haul to be measured simultaneously.

2.2.3. Statistical analyses

Species abundances (number of individuals) and biomasses (kg) were standardized to 1 km^2. Species appearing in less than 15% of the samples and those considered as pelagic or mesopelagic, and hence not clearly related to benthic habitats (i.e. *Trachurus* spp., *Spicara smaris* and *Boops boops*), were not considered. Principal components analysis (PCA) was applied to the standardized biomass of macro-epibenthic species, algae and invertebrates (Annex 2.1) in order to determine the major gradients of macro-epibenthic change. The Redundancy analysis (RDA), available in the CANOCO 4.5 package (ter Braak and Smilauer, 2002), was used to model the effect of environmental variables on the distribution of macro-epibenthic species. Unlike multivariate indirect gradient analyses, canonical analyses such as RDA provide the means for conducting direct explanatory analyses in which the association among species can be studied with respect to their common and unique

relationships with environmental variables (Peres-Neto et al., 2006). The dependent variables were the standardized biomasses (kg/km^2) of macro-epibenthic species. The depth (m) and $\bar{U}$ (cm/s), resulting from the hydrodynamic numerical model, were included in the RDA as continuous explanatory variables whereas the sampling year was included as a nominal (categorical) explanatory variable. The interaction between explanatory variables was also analyzed in the RDA model. The effect of each variable was tested using partial RDA models which allow the effect of a particular explanatory variable to be analyzed after the rest of the variables have been set as covariables (variables that are fitted to the species data before the ordination, which is carried out afterwards using only the residual variation). The significance of the models was assessed using the Monte Carlo permutation-based test (Manly, 1991). The partial effect of $\bar{U}$ on the macro-epibenthic species was plotted. Species data were square-root transformed in both the PCA and RDA.

The RDA was also used to analyse the effect of $\bar{U}$ and macro-epibenthic species on nekto-benthicnekto-benthic fish species. The dependent variables were the square-root transformed standardized abundances of fish species (individuals/km^2), and the explanatory variables were those used in the RDA applied to macro-epibenthic species ($\bar{U}$, depth and year), plus the sample scores of the first two axes resulting from the PCA of macro-epibenthic species (AXs). The two axes were used as a surrogate of the major gradient of macro-epibenthic change. The effects of $\bar{U}$ and macro-epibenthic change were plotted.

The effects of $\bar{U}$ and macro-epibenthic change on nekto-benthic fish size at a community level were investigated by using the same model scheme, but using normalized biomass spectra classes as dependent variables. To do so, the normalized biomass spectra classes of all nekto-benthic fish species were obtained on a sample basis by calculating the size frequencies of each species in each sample. Length units were then converted to weight using the available weight-length relationships in the area (Morey et al., 2003). Fish biomasses greater than 1 g, independent of the species, were aggregated within $\log_2$ size classes in grams. The biomass spectra were normalized by dividing the biomass obtained in each $\log_2$ size class by the width of the interval (calculated by doing the inverse of the $\log_2$ size classes and subtracting the value obtained by the immediately previous $\log_2$ size class). Due to the low frequency of occurrence of classes 12 and 13, they were included together in a 12+ class.

The relationship between nekto-benthic fish size and $\bar{U}$ was also studied at species level. Each sample was classified according to a rough scale of $\bar{U}$ consisting of three levels: low, medium and high. Each level corresponded to one third of the range (0.40-1.68, 1.68-2.96 and 2.96-4.24 cm/s respectively). We then calculated the length frequency distributions of each of the most abundant fish species, with at least 75 individuals collected in each level. The non-parametric two-sample Kolmogorov-Smirnov test was used to compare the length frequency distributions between levels of $\bar{U}$ for each species. As depth is known to be an important factor that affects the fish size distribution we assessed whether the depth was different between levels of $\bar{U}$ by means of analysis of variance (ANOVA).

2.3 Results

2.3.1 Macro-epibenthic species and hydrodynamics

A total of 191 macro-epibenthic species or taxons accounting for a total of 9900 kg were collected. The main groups in terms of biomass were the algae, sponges, echinoderms and crustaceans, but also molluscs, cnidarians and bryozoans. The PCA did not form groups of samples, which suggests that there is a gradual variation in species composition along the first and second axes, which accounted for 39.4 and 21.8 of the whole variance of species data respectively (Figure 2.3). The first axis was mainly correlated with the abundance of echinoderms (the sea urchin *Spatangus purpureus*, the holothurian *Stichopus regalis*, and the starfish *Astropecten aranciacus*), Paguridae decapod crustaceans (*Dardanus arrossor* and *Pagurus prideauxi*), and the sponge *Suberites domuncula*. The second axis was mainly correlated with the abundance of red algae (Corallinaceae, *Phyllophora crispa*, *Peyssonnelia* spp. and *Osmundaria volubilis*), green algae (*Codium bursa*), and brown algae (*Laminaria rodriguezii*) species, as well as ascidians (Figure 2.3).

The RDA showed that both $\bar{U}$ and depth, significantly affect the distribution of macro-epibenthic species, whereas no significant differences were found between the two years sampled. The whole model accounted for 22.5 % of the total variance of macro-epibenthic species, and $\bar{U}$ explained the most variance (Table 2.1). The partial RDA for $\bar{U}$ showed that Corallinaceae, *L. rodriguezii*, *Diazona violacea, S. purpureus and Cidaris cidaris*, were positively correlated with this variable, whereas *C. bursa*, *P. crispa*, *Axinella damicornis, Tethya aurantia*, *Botryllus schlosseri*, *Microcosmus vulgaris*, *Synoicum blochmanii*, *Ascidia mentula*, *Aplidium conicum*, *S. regalis*, and the Inachidae crab *Inachus thoracicus*, were negatively correlated with $\bar{U}$ (Figure 2.4).

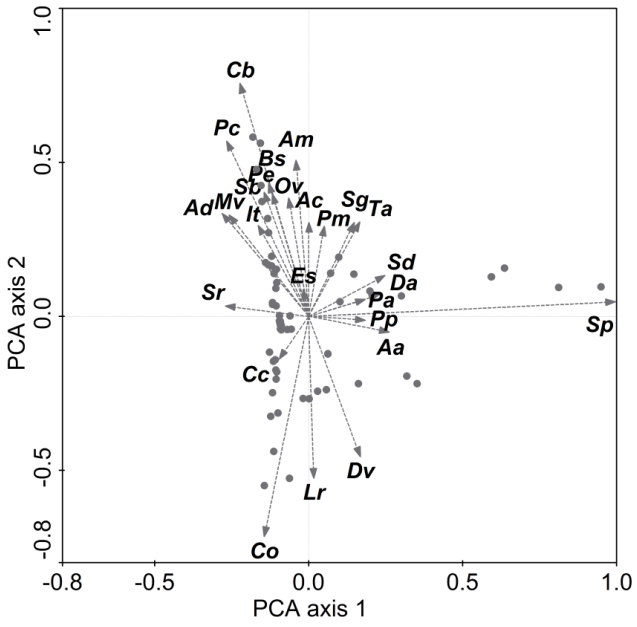


Figure 2.3. Ordination diagram of the PCA of macro-epibenthic species. Species abreviations appear in full in Annex 2.1

3.2. Fish species, macro-epibenthos and hydrodynamics

A total of 92 nekto-benthic fish species which accounted for a total of 1644 kg and 22460 individuals were collected. The RDA models showed that all the explanatory variables analyzed significantly affected the fish composition, altogether accounting for 32.9 % of the total variance in fish abundance (Table 2.2). The sum of the partial variances explained by each variable did not account for the variance explained by the whole model because some of the variance was shared by $\bar{U}$ and AXs (7.6 %). This added to the variance explained exclusively by the two variables (Table 2.2) made a total of 18.8% of variance explained by $\bar{U}$ and AXs together. Most of the species analyzed showed abundances that correlated positively with $\bar{U}$ or the second axis of the PCA for macro-epibenthic species (AX2). *Blennius ocellaris* and *Synaptura kleinii* were the species that correlated most positively with the first axis of the PCA (AX1). The mean fish weight and mean total length (Annex 2.2) showed that except for the small blennid *B. ocellaris*, the rest of the smallest species, such as *Serranus hepatus*, *Scorpaena notata*, *Arnoglossus thori*, *Deltentosteus collonianus* and *Lepidotrigla cavillone*, were positively correlated with AX2 and negatively correlated with $\bar{U}$ and AX1 (Figure 2.5).

Table 2.1. Results of the redundancy analysis applied to macro-epibenthic species biomass. The variance explained by each explanatory variable and by the whole model (including all significant explanatory variables) is indicated. The F-ratio and the p-value after 999 permutations are also shown. *: p< 0.05, **: p< 0.01, n.s.: non-significant. The interactions between the explanatory variables were also analyzed but not included in the final model because they were not significant.

Explanatory variables	Variance explained (%)	F-ratio	p
Year	1.3	0.99	n.s.
Depth	10.2	7.62	**
$\bar{U}$	12.3	9.19	**
Whole	22.5	7.99	**

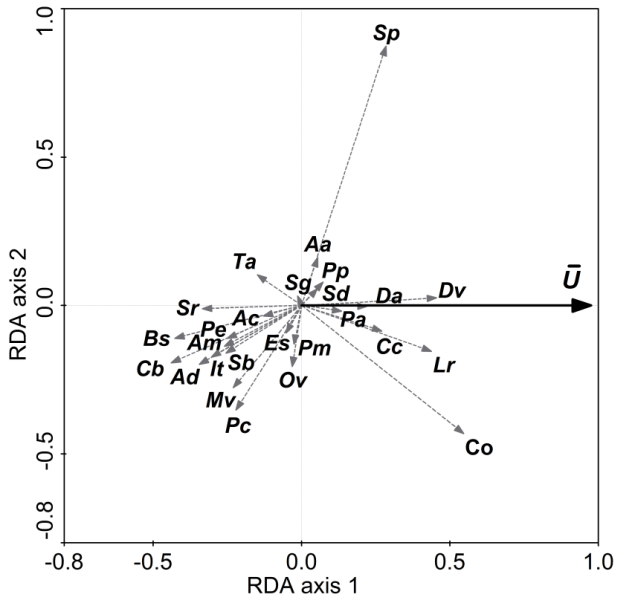


Figure 2.4. Ordination diagram corresponding to the partial RDA analyzing the effect of $\bar{U}$ on macro-epibenthic species. The rest of the explanatory variables were set as covariables. Species abbreviations appear in full in Annex 2.1.

The RDA applied to the biomass spectra classes explained 39.3% of the total variance, and all the explanatory variables included were significant (Table 2.2). As for the analysis of fish species, there was a percentage of the explained variance that was shared by AXs and $\bar{U}$. In this case it was 11.1 %, which added to the variance explained exclusively by the two variables (Table 2.2) made a total of 23.4% of variance explained by $\bar{U}$ and AXs together. The plot showed that the abundance of the smaller size classes (0 to 5) was negatively correlated with $\bar{U}$ and AX1, and positively correlated with AX2. The abundance of medium and large size classes (6 to 12+) was positively correlated with $\bar{U}$ and AX1 (Figure 2.5).

Table 2.2. Results of the redundancy analysis applied to fish species abundance and fish biomass spectra classes. The variance explained by each explanatory variable and by the whole model (including all significant explanatory variables) is indicated. The F-ratio and the p-value after 999 permutations are also shown. *: p< 0.05, **: p< 0.01, n.s.: non-significant. The interactions between the explanatory variables were also analyzed but were not included in the final model because they were not significant.

Fish species abundance			
Explanatory variables	Variance explained (%)	F-ratio	p
Year	6.7	5.52	**
Depth	7.4	6.69	**
$\bar{U}$	3.1	2.59	*
AX's	8.1	3.35	**
Whole	32.9	5.34	**

Fish biomass spectra classes			
Explanatory variables	Variance explained (%)	F-ratio	p
year	10.4	9.62	**
Depth	5.5	5.06	**
$\bar{U}$	4.1	3.80	**
AX's	8.2	3.78	**
Whole	39.3	7.26	**

The Kolmogorov-Smirnov test comparing the length frequency distributions of the most abundant fish species between $\bar{U}$ levels showed significant differences for *A. thori*, *M. surmuletus*, *C. Lastoviza*, *S. cabrilla* and *S. canicula*. All of these species, except *S. canicula* showed the same trend: small individuals were more important in the length frequency distributions corresponding to the low and/or medium $\bar{U}$ levels than in the high level (Figure 2.6). A similar trend was also found for *T. draco*, although it was not significant. Small individuals of *S. canicula* were more important in low and high $\bar{U}$ levels than in the medium level. The mean depth of the three levels of $\bar{U}$ (65.1 ± 2.5, 63.4 ± 4.1 and 68.3 ± 2.3 for low, medium and high respectively) did not show significant differences ($F_{2, 59}$= 2.12, p= 0.13).

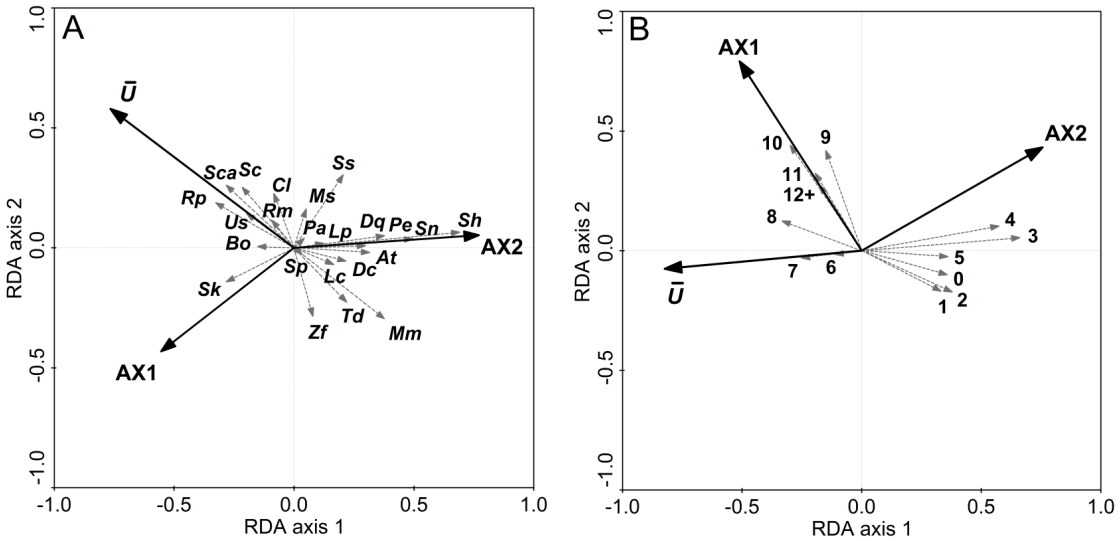


Figure 2.5. Ordination diagrams corresponding to the partial RDA analyzing the effects of U and AXs (the sample scores of the two principal components of the PCA carried out on macro-epibenthic species) on fish species (A) and fish biomass spectra classes (B). The rest of the explanatory variables were set as covariables. Species abbreviations appear in full in Annex 2.2.

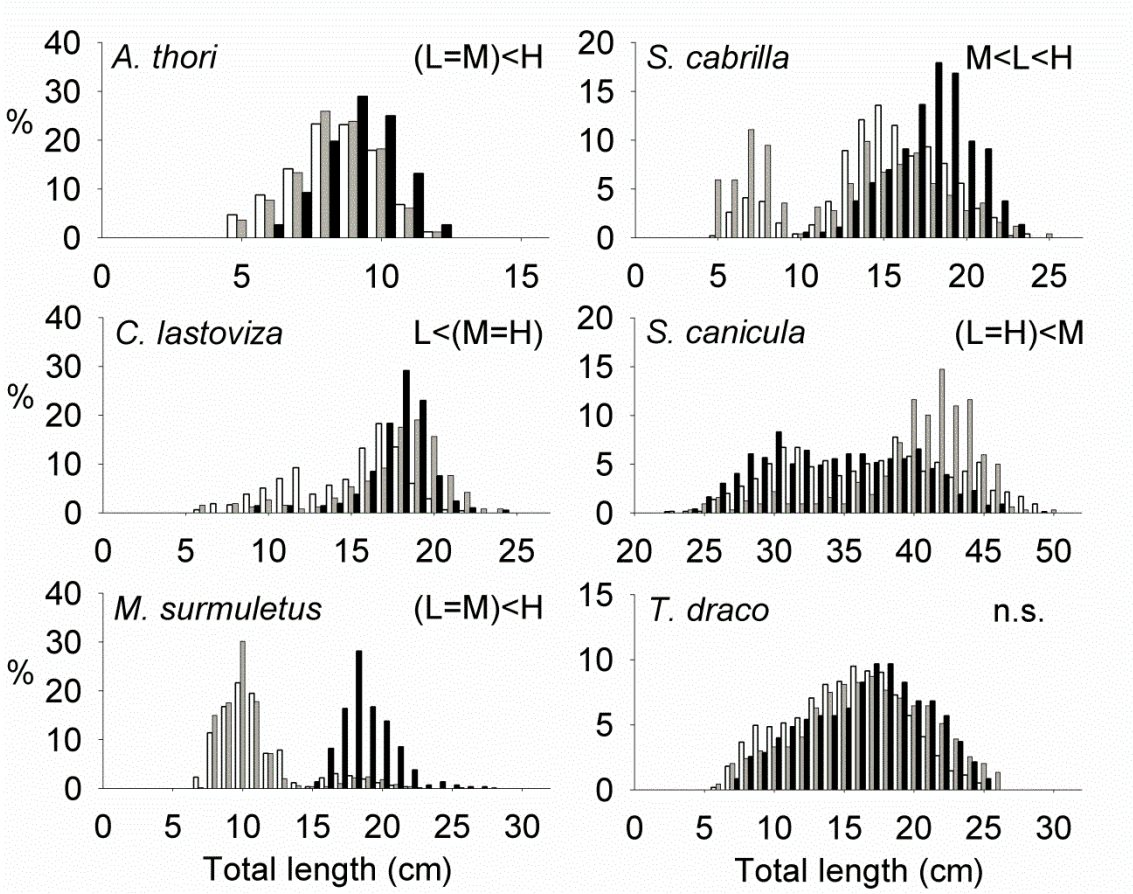


Figure 2.6. Length frequency distributions of the most abundant fish species for each $\bar{U}$ level. The interpretation of the two-sample Kolmogorov-Smirnov test based on significant differences at p-values< 0.05 is also shown. Different colours indicate different $\bar{U}$: white (low, L), grey (medium, M) and black (high, H).

2.4 Discussion

The coastal detritic bottom communities of the Mediterranean extend from below 40 to 95 m depth in areas with little deposition of fine sediments (Pérès, 1985). The present study revealed that the macro-epibenthic species inhabiting these depths off the Balearic Islands have a wider distribution than that previously reported in the area (Ordines and Massutí, 2009). In the previous study, the *Peyssonnelia* and maërl beds appeared as different and geographically separated macro-epibenthic landscapes, whereas the present work shows a progressive change from one landscape to another. The PCA ordination showed a first axis that was mainly related to the abundance of echinoderms and Paguridae crabs. The second axis was related to the abundances of species typifying maërl beds, such as Corallinaceae and *Laminaria rodriguezii*, and *Peyssonnelia* beds, such as *Peyssonnelia* spp. *Codium bursa*, *Phyllophora crispa*, *Osmundaria volubilis* and most of the invertebrates (Pérès, 1985; Ballesteros, 1994; Ordines and Massutí, 2009). Hence, our samples were distributed between the two main red algae facies described in the western Mediterranean, and a range of transition landscapes where species such as *Spatangus purpureus* can reach large abundances, as previously reported by Pérès (1985) and Ordines and Massutí (2009).

The hydrodynamics were more important than depth for the distribution of macro-epibenthos, and species typifying both maërl and *Peyssonnelia* beds appeared positively and negatively correlated with $\bar{U}$ respectively. However, the large amount of variance the model did not explain (77%) indicates that other factors that are not taken into account in our analyses also influence the distribution of these species. Maërl beds off Mallorca Island are mainly located in the Menorca channel, whereas *Peyssonnelia* beds are located in the southern coast (Ordines and Massutí, 2009). The hydrodynamic model results show the highest values of $\bar{U}$ in the Menorca channel and its nearby area. This area is also open to the predominant northerly winds and the largest storms in the area, which are considered to be favourable events for the development of maërl beds (Basso, 1998; Sciberras et al., 2009). Water movement is considered a key factor in the distribution of Corallinaceae, which are generally found in areas of moderate to strong seabed currents that prevent burial (Marrack, 1999; Wilson et al., 2004) and provide frequent overturning that keeps living algal surfaces all around the rhodoliths (Basso, 1998). However, the lowest values of $\bar{U}$ were predicted in the south of Mallorca Island, an area at the lee of the northerly winds. The distribution of the *Peyssonnelia* beds in the Mediterranean Sea has been related to open bays with fine sediments, even mud, where calm periods alternate with periods of eddy forming currents (Pérès, 1985; Bordehore et al., 2003). *C. bursa*, one of the most important species in terms of biomass in *Peyssonnelia* beds but barely present in maërl beds (Ordines and Massutí, 2009), attaches weakly to the substrate, which makes it highly sensitive to bottom instability, such as that caused by moderate currents (Sciberras et al., 2009). In particular, in the Balearic Islands, *Peyssonnelia* beds have been related to the presence of sand waves, which suggests that algal populations concentrate in the wave depressions (Ballesteros, 1994). The southern shelf off Mallorca is characterized by a series of fairly continuous and complex bars, roughly parallel to the coastline (Acosta et al., 2002), which create submarine terraces that, along with the presence of

sand waves, could favour the presence of *Peyssonnelia* beds. Hence, the role of $\bar{U}$ as a physical driving force of species change from one landscape to another seems to be enhanced by the co-existence with other favourable environmental settings, altogether allowing a range of transition landscapes, which has already been described in the area for algal communities (Ballesteros, 1994).

Warwick and Uncles (1980) established a direct correlation between faunal type and current speed. They reported a reduction in sessile fauna species at high current speeds, and hypothesized that this was "undoubtedly related to the relative abilities of species to maintain a foothold". Our results fit well within this hypothesis because most of the sessile animals, such as sponges and ascidians, were negatively correlated with $\bar{U}$. In fact, the only two ascidia species found to be positively correlated with $\bar{U}$ were *Diazona violacea*, a colonial ascidia with an affinity for current-swept surfaces (Berrill, 1950) which develops the largest foothold among the ascidians present in the samples, and *Polycitor adriaticum*, which preferentially inhabits areas that are very exposed to currents (Naranjo, 1996).

Both the $\bar{U}$ and the main gradients of macro-epibenthic change significantly affected the distribution and attributes of the demersal fish species and assemblages. Most fish species preferred the more vegetated bottoms of either the maërl or *Peyssonnelia* beds, the exceptions being *Synaptura kleinii*, a sole typical of sandy bottoms that would find more favourable conditions in less vegetated areas, and the blennid *Blennius ocellaris*. Overall, most of the smallest fish species correlated negatively with $\bar{U}$ and had an affinity for *Peyssonnelia* beds. The same pattern appeared at the community and fish species levels. The most abundant fish species showed more small individuals on bottoms with low and medium levels of $\bar{U}$, and were consequently related to bottoms that were most similar to *Peyssonnelia* beds. The only exception was *Scyliorhinus canicula*, the species showing the widest depth range of all the species analyzed, whose recruits and juveniles inhabit deeper bottoms than the ones sampled here (shelf break and upper slope; Massutí and Moranta, 2003).

Maërl beds reach high degrees of three-dimensional structural complexity (Steller et al., 2003). However, this does not seem to be advantageous enough for small-sized individuals and species, which are more abundant in calm waters with *Peyssonnelia* beds. It is difficult to determine the specific contribution of the hydrodynamics and benthic landscape to the distribution of small individuals/species due to the correlation shown by these two factors. Small individuals and species would be weaker swimmers than larger species, which may condition their ability to survive in areas exposed to larger hydrodynamic disturbances. The benthic landscape and its structural complexity may also be important. Small individuals and species may find more sheltering and feeding opportunities in *Peyssonnelia* beds, which bring together high benthic production and an important erect algae stratum provided by *P. crispa* and *O. volubilis* (Ballesteros, 1994; Ordines and Massutí, 2009). The survivorship of small fish individuals and species has been reported to be strongly linked to the availability of areas with high structural complexity and benthic production. Connell and Jones (1991) showed that the mortality of post-recruits of a small blennioid species increased to 100% in habitats with low

structural complexity compared to 13% in habitats with high complexity. The structural complexity provided by macroalgal assemblages has also been reported to play a major role in structuring fish communities by enhancing the abundance of recruits and juveniles (Carr, 1989; Levin and Hay, 1996). Moreover, Edgar and Shaw (1995) showed that seagrass beds enhance the production of epifauna and support over twice the production of small fish than unvegetated bottoms. In the Mediterranean, *Posidonia oceanica* meadows provide morphologically complex systems (Mazzella et al., 1993) on coastal bottoms. In sheltered conditions these meadows are essential habitats because they act as nurseries for several fish species (Francour and Le Direac'h, 1994; Harmelin-Vivien et al., 1995; García-Rubies and Macpherson, 1995; Guidetti, 2000). In this area, calm weather conditions have been reported to increase the settlement success in coastal algal accumulations (Raventos and Macpherson, 2005). Hence, the sheltered conditions (low hydrodynamics) that favour the presence of *Peyssonnelia* beds could lead to these bottoms playing a similar role to that of *P. oceanica* meadows and coastal algal accumulations, but in deeper waters.

Size is an important factor for the fish swimming performance, and smaller individuals have slower swimming speeds compared to larger conspecifics (Vogel, 1994). This fact has been hypothesized to be a possible explanation for the ontogenetic differences in habitat use of small coral reef fish at a microhabitat scale, with smaller and slower swimming individuals mainly found in areas that are sheltered from water flow, and larger species found in more exposed conditions (Fulton and Bellwood, 2002). Moreover, at a small scale the larger and heavier individuals of small coral reef fish communities predominate in high hydrodynamic zones, whereas smaller and lighter ones are commonly found in calmer waters (Depczynski and Bellwood, 2005). Small individuals and species seem to inhabit non-exposed sites and sheltered substrata with reduced flow in order to avoid the need for excessive swimming activity to conduct their daily activities (Fulton and Bellwood, 2002; Depczynski and Bellwood, 2005). The case of the Balearic Islands continental shelf might be a simple extension to the medium spatial scale (tens of km) of what occurs at the micro and small scale at intra-specific and community levels in coral reefs; however, in this case, the hydrodynamic gradient is provided by the current velocity instead of wave exposure. The benefits for small individuals and fish species of inhabiting lower $\bar{U}$ areas with *Peyssonnelia* beds that provide high structural complexity not only include saving energy and being sheltered, but also small fish could keep their best swimming performance for escaping from larger predators that are able to maneuver more efficiently even in high hydrodynamic conditions.

Our results support that the hydrodynamics have a strong influence on the benthic landscape, and show how these two habitat traits affect the composition and attributes of the associated fish communities, including some commercially important species. The connections between the abiotic and biotic characteristics, such as those presented here, can be used to determine models based on 'physical' datasets that aim to predict the distribution of sensitive or essential fish habitats, or even to determine where they should be located in heavily exploited areas that are to be recovered. Our findings are also important in the application of ecosystem-based fisheries management,

especially in the current context of protecting particular habitats and creating marine protected areas. The European directive EC-1967/2006, which concerns management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, protects maërl beds. In areas such as the Balearic Islands (as in most of the Mediterranean), where there is no officially mapped distribution of this community, trawlers can still fish on these bottoms. Applying this policy, based on proper distribution maps, could imply relocating the fishing effort to nearby open areas. Relocating the fishing effort due to the creation of marine protected areas can have contrary effects to those expected from protection on the remaining fishing areas if these areas contribute to the maintenance of juvenile fish populations (Suuronen et al., 2010). This may be the case of areas characterized by weak currents and *Peyssonnelia* beds, which bring together high productivity and structural complexity, and therefore provide good conditions for the shelter and growth of small species and juvenile fish. Hence, in areas where different bottom communities and hydrodynamic regimes can be found at the medium spatial scale, protection of particular habitats should be done with the maximum precaution in order to avoid undesirable collateral effects in other nearby essential habitats.

Annex 2.1. Key for macro-epibenthic species abbreviations.

Taxonomy	Abbreviations	Macro-epibenthic species
Algae	*Cb*	*Codium bursa*
	Co	Corallinaceae
	Lr	*Laminaria rodriguezii*
	Ov	*Osmundaria volubilis*
	Pc	*Phyllophora crispa*
	Pe	*Peyssonnelia* spp.
Ascidian	*Ac*	*Aplidium conicum*
	Am	*Ascidia mentula*
	Bs	*Botryllus schlosseri*
	Dv	*Diazona violacea*
	Mv	*Microcosmus vulgaris*
	Pa	*Polycitor adriaticum*
	Pm	*Phallusia mamillata*
	Sb	*Synoicum blochmani*
Decapod crustaceans	*Da*	*Dardanus arrosor*
	It	*Inachus thoracicus*
	Pp	*Pagurus prideauxi*
Echinoderms	*Aa*	*Astropecten aranciacus*
	Cc	*Cidaris cidaris*
	Es	*Echinaster sepositus*
	Sg	*Sphaerechinus granularis*
	Sp	*Spatangus purpureus*
	Sr	*Stichopus regalis*
Esponges	*Ad*	*Axinella damicornis*
	Sd	*Suberites domuncula*
	Ta	*Tethya aurantium*

Annex 2.2. Key for fish species abbreviations. The mean fish weight (g) and total length (mm), calculated as the averages of all individuals, are indicated by each species. Standard deviations are shown between brackets.

Abb.	Fish species	Mean weight	Mean TL
At	*Arnoglossus thori*	6.3 (3.8)	84 (18)
Bo	*Blennius ocellaris*	28.6 (13.7)	122 (28)
Cl	*Chelidonichthys lastoviza*	53.2 (26.7)	164 (35)
Dc	*Deltentosteus collonianus*	1.5 (0.8)	56 (9)
Dq	*Deltentosteus quadrimaculatus*	2 (1.5)	59 (13)
Lc	*Lepidotrigla cavillone*	14.2 (7.1)	103 (16)
Lp	*Lophius piscatorius*	443.2 (571.5)	259 (119)
Mm	*Merluccius merluccius*	62.3 (69.9)	196 (48)
Ms	*Mullus surmuletus*	33.3 (34.2)	129 (44)
Pa	*Pagellus acarne*	39.7 (28.4)	143 (32)
Pe	*Pagellus erythrinus*	83.1 (48)	180 (36)
Rm	*Raja miraletus*	194.3 (104.4)	323 (70)
Rp	*Raja polystigma*	448 (289.6)	410 (75)
Sn	*Scorpaena notata*	29.8 (15.1)	114 (20)
Sp	*Scorpaena porcus*	86.8 (47.7)	163 (25)
Ss	*Scorpaena scrofa*	162.2 (138.8)	195 (58)
Sca	*Scyliorhinus canicula*	156 (77.9)	365 (58)
Sc	*Serranus cabrilla*	48 (31.7)	154 (43)
Sh	*Serranus hepatus*	8.9 (3.9)	81 (14)
Sk	*Synaptura kleinii*	531.5 (189)	280 (36)
Td	*Trachinus draco*	31.3 (23)	159 (43)
Us	*Uranoscopus scaber*	139.3 (101.8)	195 (38)
Zf	*Zeus faber*	161.3 (413.8)	160 (100)

CHAPTER 3

Influence of benthic habitats on the condition of nekto-benthic fish

3.1 Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*

3.2: Red algae beds increase the condition of nekto-benthic fish

3.1 Adapted from: **Ordines F.**, Quetglas A., Massutí E., Moranta J. (2009). Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. *Estuarine, Coastal and Shelf Science* 85: 537-546. doi: 10.1016/j.ecss.2009.09.020

3.2 Adapted from: **Ordines F.**, Bauzá M., Sbert M., Roca P., Gianotti M., Massutí E. (2014). Red algae beds increase the condition of nekto-benthic fish. *Journal of Sea Research* 95: 115-123. doi: 10.1016/j.seares.2014.08.002

Chapter 3: Influence of benthic habitats on the condition of nekto-benthic fish

3.1 Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*

Abstract

In the Balearic Islands, the coastal continental shelf bottoms are characterised by the presence of the facies with red algae. These beds enhance the structural complexity, biodiversity and secondary production of the soft bottoms. The present work studies the biology of *Scorpaena notata* and its relationship with these red algae beds in the bottom trawl fishery. The reproduction period of *S. notata* in the Balearic Islands occurs in summer and is accompanied by a decrease in hepatic condition, as it happens in the adjacent area off the Iberian Peninsula; however, in contrast with this adjacent area, this period is accompanied by a decrease in somatic condition and an increase in feeding potential, which suggests that these could be adaptations to the higher oligotrophy of the Archipelago. The standardised algal biomass (mostly Rhodophyceae) present in the studied bottoms positively affects the abundance, somatic condition and feeding potential of *S. notata*. Individuals inhabiting bottoms with the highest algal biomass showed faster growth than the entire population analysed together. Both, the structural complexity and the availability of preys in the facies with red algae are revealed as advantageous traits for the life history of fish. Taking into account the importance of individual health for the overall success of the population, the indexes studied here could be a useful tool for identifying high quality or essential fish habitats. The results highlight the role of the facies with red algae as oasis of high productivity where benthic fish can circumvent the general oligotrophic conditions of the Mediterranean, and the necessity of urgent management measures in order to protect them from human impacts.

Keywords: *Scorpaena notata*; life history; habitat selection; body condition; feeding behaviour.

Capítol 3: Influència dels hàbitats bentònics en la condició dels peixos necto-bentònics

3.1 Biologia i preferències d'hàbitat del cap-tinyós, *Scorpaena notata*

Resum

A les Illes Balears, els fons de la plataforma costanera es caracteritzen per la presència de facies d'algues vermelles. Aquestes comunitats augmenten la complexitat estructural i la producció secundària dels fons tous. Aquest treball estudia la biologia de *Scorpaena notata* i la seva relació amb aquests fons a la pesquera de ròssec. El període de reproducció de *S. notata* a l'Arxipèlag té lloc durant l'estiu, coincidint amb una davallada de la condició hepàtica, de forma semblant al que ocorre a l'àrea adjacent de la península Ibèrica; no obstant això, contràriament al que ocorre a la Península, aquest període va acompanyat d'una davallada de la condició somàtica i un increment del potencial d'alimentació, suggerint que ambdues podrien tractar-se d'adaptacions a l'oligotròfia més accentuada de l'Arxipèlag. La biomassa algal estandarditzada (majoritàriament Rhodophyceae) present als fons estudiats afecta positivament l'abundància, condició somàtica i el potencial d'alimentació de *S. notata*. Els individus que habiten els fons amb la biomassa algal més elevada mostraren un creixement més ràpid quan foren comparats amb tota la població analitzada conjuntament. Tant la complexitat estructural com la disponibilitat de preses a les facies amb algues vermelles apareixen com a característiques avantatjoses pel cicle vital dels peixos. Tenint en compte la importància de la salut dels individus per l'èxit de tota la població, els índexs estudiats al present treball podrien ser una eina útil a l'hora d'identificar hàbitats essencials o d'alta qualitat. Els resultats remarquen el paper de les facies amb algues vermelles com a oasis de producció elevada on els peixos bentònics poden fer front a les condicions oligotròfiques que es donen arreu del Mediterrani, així com la necessitat de prendre mesures urgents amb l'objectiu de protegir-les d'impactes antropogènics.

Paraules clau: *Scorpaena notata;* biologia; selecció d'hàbitat; condició; alimentació.

3.1.1 Introduction

During the last decade, there has been a growing interest in the ecosystem approach to fisheries (EAF), which integrates biology, fishing exploitation and ecosystem aspects to assess and manage marine resources (Browman and Stergiou, 2004). Hence, its application depends upon the existing bio-ecological knowledge of the species involved, including information on the target species and non-target species of fisheries, and other components of the ecosystems such as the habitat, which can be critical for population processes (Pickitch et al., 2004). The sustainability of a highly multi-species fishery, like the Mediterranean bottom-trawl fishery, depends on a large number of different species, many of which are caught as by-catch (Moranta et al., 2008). Hence, acquiring knowledge on the biology and habitat relationships of these species is necessary in order to apply the EAF in this area.

The waters around the Balearic Archipelago, where there is no supply of nutrients from river runoff, show more pronounced oligotrophy than the adjacent waters off the Iberian coast and the Gulf of Lions (Estrada, 1996). The sediments on the Balearic shelf are mainly biogenic sands and gravels (Acosta et al., 2002), and because of the clear waters here, the algae beds can grow down to a depth of 90-100 m (Ballesteros, 1992, 1994), forming red algal facies at the trawl fishing grounds (Ordines and Massutí, 2009). The macro-algae meadows, and their drifting accumulations are associated to high levels of biodiversity of both algae and animal species that take advantage of the structural characteristics of these grounds, fuelling higher trophic levels (Vetter, 1995; Vetter and Dayton, 1998; Steller et al., 2003; Bordehore et al., 2003; Hinojosa-Arango and Riosmena-Rodriguez, 2004; Norkko et al., 2004). In the Balearic Islands the *Peyssonnelia* and mäerl beds are the two predominant facies and cover large areas of sea bottom between 40-90 m. The *Peyssonnelia* beds are mainly distributed at the south and southeast Mallorca and south Menorca (Ballesteros, 1994; Ordines and Massutí, 2009), and to our knowledge, they display the highest average of algae biomass and coverage reported in the western Mediterranean soft bottoms (Ballesteros, 1994; Bordehore et al., 2003), which are even higher than the average plant biomass from Mediterranean upper-circalittoral rocky bottoms (Ballesteros, 1994). *Peyssonnelia* beds are characterised by a high abundance of free living Peyssonneliaceae species, accompanied by abundant erect red algae species such as *Osmundaria volubilis* and *Phyllophora crispa*, and Corallinaceae species such as *Lithothamnion valens* and *Phymatolithon calcareum* (Ballesteros, 1994). The mäerl beds are mainly located in the channel between Mallorca and Menorca and display a predominance of the Corallinaceae species cited above, with an erect stratum dominated by the large kelp *Laminaria rodriguezii* (Pérès, 1967; Pérès and Picard, 1964; Ballesteros, 1994; Ordines and Massutí, 2009). In spite of the importance of red algae beds and their fragility (Barbera et al., 2003), they are threatened by different human activities such as trawling. The physical action of the gear and the metal boards used in this fishing modality affects directly the algal beds by fragmentation and removing large amounts of algal biomass, and indirectly by causing sediment suspension and the subsequent light reduction and siltation (Carbonell, 1998; Bordehore at al., 2003; Ordines et al., 2006).

Essential fish habitats are those that are advantageous (and even vital) for the success of exploited species, in terms of reproduction, survival and growth (e.g. Botsford et al., 1997; Benaka, 1999; Fogarty, 1999; Rosenberg et al., 2000), and their identification constitutes a keystone towards the development of sustainable fisheries (Benaka, 1999). The existence of high quality habitats has been reported as a factor that positively impacts fish condition (Lloret and Planes, 2003; Somarakis et al., 2004; Levi et al., 2005; Pothoven et al., 2006). The vital processes are also expected to be influenced by the fitness and health of the individuals (Marshall and Frank, 1999; Marshall et al., 1999; Shulman and Love, 1999).

The red scorpion fish, *Scorpaena notata*, is a benthic, small-sized scorpion fish which occurs in the Mediterranean and adjacent areas of the Atlantic, from the Bay of Biscay to Senegal, Madeira, the Azores and the Canary Islands (Hureau and Litvinenko, 1986). In the western Mediterranean this species mainly inhabits coastal waters, from the surface down to 150 m depth (Harmelin, 1987; Harmelin-Vivien et al., 1989). In some littoral communities, such as rocky reefs and *Posidonia oceanica* beds, Scorpaenidae is among the most important fish families in terms of biomass. Within this family on these bottoms, *S. notata* has been ranked second in importance (Harmelin-Vivien et al., 1989), and is the most abundant scorpion fish in the circalittoral soft sediment communities with red algae (Ordines and Massutí, 2009). In the Mediterranean, it is a by-catch species along its whole bathymetric distribution range, from littoral bottoms, where it is caught with trammel nets, to deeper bottoms, where it is caught by trawling. Some aspects of the biology of *S. notata* have been studied in the Mediterranean, such as growth (Bradai and Bouain, 1990a), diet (Harmelin et al., 1989; Morte et al., 2001), gonad morphology (Muñoz et al., 2002a, 2002b), fecundity and reproductive cycle (Muñoz et al., 2005). However, these studies only cover separate aspects of the biology of the species and, to our knowledge, there is also a lack of information on the relationships between its biological parameters and the habitats in which it is distributed.

Therefore, the present paper aims to make a complete study of the population dynamics and the biological parameters of *S. notata* off the Balearic Islands. It also provides an in-depth analysis of those aspects related to fish condition and their relationship with internal (physiological processes such as feeding, growth and reproduction) and external (habitat characteristics, which can determine structural complexity and productivity) factors. The clear sedentary characteristic of the red scorpion fish (Harmelin, 1987), and the massive presence of the facies with red algae in our study area, make possible the analysis of the influence of this habitat on the abundance and condition of *S. notata*. Finally, our results are compared with those from studies carried out in the more productive adjacent waters off the Iberian coast and the Gulf of Lions (Harmelin et al., 1989; Morte et al., 2001; Muñoz et al., 2002a, 2002b, 2005).

3.1.2 Material and methods

3.1.2.1 Sampling

Data and samples were collected from two different sources: 1) annual experimental trawl surveys carried out in the Balearic Islands in spring 2004, 2005 and 2006, which covered the shelf and slope, and autumn in 2004 and 2005, which covered the shelf down to 100 m depth; and 2) monthly sampling on board the commercial trawling fleet during the same period (Figure 3.1.1). The sampling scheme and gear (GOC73) used in the experimental surveys were those used most commonly since 1994 throughout the northern Mediterranean (Bertrand et al., 2002). The experimental hauls were conducted during daylight hours, with durations of 20 to 60 minutes, depending on the depth. The average towing speed was 2.8 knots. The arrival and departure of the net to the bottom, as well as its horizontal and vertical openings (on average, 16.4 and 2.8 m respectively) were measured using a SCANMAR system. A total of 260 experimental hauls, between 38 and 755 m depth were analysed. In each sample, abundance, biomass and length frequency of *Scorpaena notata* were determined and standardised to one square km by using the distance covered and the horizontal opening in each haul. Furthermore, biological samplings were carried out on representative samples for which the following variables were recorded: sex, maturity stage, total length (TL, to the nearest mm), total weight (TW), eviscerated weight (EW), gonad weight (GW), digestive tract weight (DW= stomach + intestine + food content) and liver weight (LW). Weights were measured to the nearest 0.01 g. If the liver was damaged at all, which was usual in individuals from commercial hauls, its weight was not recorded. In total, 947 biological samplings were carried out. The sagittal otoliths of all these individuals were also removed, cleaned and stored dry in envelopes. Algae species were also separated and weighed on board, and the standardised algal biomass (kg/km^2) was calculated following the same methodology used to standardise the abundance of *S. notata.*

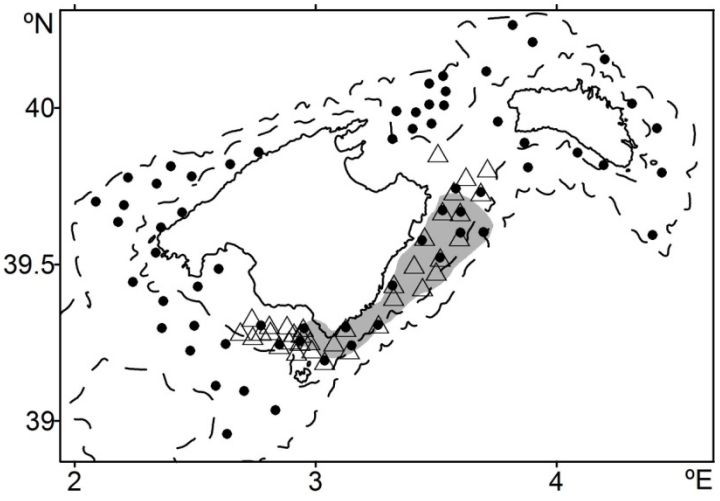


Figure 3.1.1. Map of the study area. Dots and triangles represent hauls carried out during the 2006 spring survey and the 2005 autumn survey, respectively. The grey area is the area operated by the south Mallorca trawling fleet, which was the source for commercial samples.

3.1.2.2 Age and growth

The otoliths were immersed in a 50% mixture of glycerol-alcohol and the number of translucent rings was counted with a compound microscope using reflected light, following standard techniques (Morales-Nin, 1987). The marginal

increment analysis was used to verify the increment periodicity of the rings (Morales-Nin, 1992). Once the rings were considered to be annual, each specimen was assigned to a year class, taking into account the date of capture, the number of rings, their formation period and the spawning season in the area.The von Bertalanffy growth function (VBGF) was fitted to the observed length-at-age data by using non-linear regression procedures in the INBIO R package (Sampedro et al., 2005). The maximum length observed in all surveys (17.9 cm) was set as L_∞.

3.1.2.3 Biological parameters and indexes

A binocular microscope was used to determine the sex and maturity stage. For females, four maturity stages were distinguished: (1) immature/inactive, with small and reddish gonads; (2) maturing, with pinkish and larger gonads, visibly bumpy; (3) mature, with oocytes hydrated and easily visible with the naked eye; (4) post-maturity, with the size of gonads similar to the previous stage, but flabby and reddish, and still containing some oocytes. For males, it was not possible to determine a maturity scale, and a rough classification that considers two stages was used: (1) immature/inactive, with thread-like and small reddish gonads; and (2) active, with wider and longer pinkish gonads, which had enlarged ducts connecting the gonad with the exterior.

The reproductive period was assessed from the seasonal evolution of the gonadosomatic index (GSI), calculated as follows: $\mathrm{GSI} = 100 * \mathrm{GW}/\mathrm{EW}$. Length at first maturity (at which 50% of the individuals are mature, L_{50}) was calculated for females, males and both sexes together from the logistic curve $\mathrm{PL} = \mathrm{e}^{(\mathrm{a}+\mathrm{b}*\mathrm{L})}/(1+\mathrm{e}^{(\mathrm{a}+\mathrm{b}*\mathrm{L})})$, where PL is the proportion of mature individuals for a given size class L, and *a* and *b* are the curve parameters to be estimated. The individuals used for this analysis (161 females and 166 males) were those collected during the spawning period, attending to the evolution of the GSI in our area, and the literature (Muñoz et al., 2005). Fitting of the logistic curves was carried out by maximising the log-likelihood function using SOLVER in EXCEL. The overall and seasonal length frequency distributions by sex were calculated and the Chi-square test was used to determine whether the sex-ratio, by length interval and by season, deviated from 1:1.

Length-weight relationships were established by power regression for males and females separately. Differences between sexes were tested by applying analysis of covariance (ANCOVA) to the log-transformed data. When no difference between sexes was found, relationships were calculated for the whole population. The 95% confidence intervals of the b parameter were calculated by using the regression analysis tool included in EXCEL, and it were used to assess the allometry of the increase in weight (confidence intervals lower/higher or including 3 indicate negative/positive or isometric growth, respectively).

Size-independent measures of somatic (SC) and hepatic (HC) condition were calculated as follows. First, the log-transformed linear relationship was applied, on an individual basis, to obtain the predicted log(EW) and log(LW). Then, the residuals, or differences between the log-transformed observed and predicted weight, were calculated and standardised, dividing each by the

standard deviation of their predicted values. An individual that is lighter for its length than predicted from the regression equation will have a negative residual, and is assumed to be in poorer condition than one that is heavier for its length than predicted from the regression equation, which will have a positive residual (Hayes and Shonkwiler, 2001). The feeding potential (FP) and reproductive condition (RC) were calculated following the same procedure, but using the residuals resulting from the DW-TL and GW-TL log-transformed relationships. The analysis of variance (ANOVA) was used to test for seasonal differences in the mean value of the indexes.

To explore possible associations between RC and SC, HC and FP, these indexes were correlated with each other (RC-SC, RC-HC and RC-FP) and the resulting regressions were analysed. Only mature females were used in these analyses and therefore the length-weight relationships were re-calculated taking only these females into account.

3.1.2.4 Abundance, fish condition, growth and habitat

The relationship between the condition of *S. notata* and the habitat characteristics was modelled by multiple regression analysis. To do so, the SC, HC and FP of each individual were recalculated from the data obtained during the experimental spring and autumn surveys separately, in order to factor out the effect of season on these indexes. The standardized algal biomass (kg/km^2) was considered as a proxy to benthic habitat structural complexity and productivity. The RC could not be tested due to the low abundance of mature females in the surveys. The multiple regression models were applied to test the effect of the algal biomass and depth on the standardised abundance (n/km^2) of *S. notata* and the mean values of SC (SC_m), HC (HC_m) and FP (FP_m) per haul. Variables were log-transformed in order to meet the assumption of linearity. The multiple regression methodology was applied after checking the non existence of spatial autocorrelation of the samples. To do so, omnidirectional variograms were created for each index analyzed. Spatial patterns were not observed even at the shortest distances and samples were assumed to be spatially independent. The standardized regression coefficients (β), which allow the relative contribution of each independent variable to the prediction of the dependent variable to be compared, were calculated. The predictor variables were checked for co-linearity before the multiple regressions were applied. The log-transformed algal biomass and depth were not correlated with each other and no significant relationship was detected (R^2= 0.05, $F_{1, 95}$= 2.56; p> 0.11).

When the regression was significant, a bubble map representing the values of the dependent variables was plotted over the contour map showing the standardised algal biomass. Contour maps were created by applying the inverse squared distance gridding method, available in SURFER 8.0, to the algal biomass indexes per haul for all the experimental surveys.

In order to investigate the effect of habitat on the growth of *S. notata*, the value of the k parameter (rate of growth towards asymptote) of the VBGF was calculated for individuals inhabiting the bottoms with the highest algal biomass, and was compared to that resulting from all the individuals analysed in the present study. To do so, the INBIO R package (Sampedro et al., 2005) was

used to re-sample both population groups (algae bottoms and total) by performing 1000 bootstraps on each. Then, *k* was calculated for each bootstrap, and a t-test was used to compare the mean values of *k* between population groups. The procedure and the value of L_∞ used to fit the VBGF were the same than those described for the entire population.

3.1.3 Results

Data collected during the experimental surveys showed that *Scorpaena notata* was present from the shallowest stations at 38 m down to 97 m depth. In this bathymetric range, the frequency of appearance was 64%, with a mean abundance of 265.5±41 individuals/km^2, and a maximum abundance of 3414 individuals/km^2, recorded in a haul at 70 m depth.

3.1.3.1 Age and growth

The otoliths showed the typical pattern for teleosts: alternations of translucent and opaque rings laid down around an opaque nucleus. The evolution over time of the incidence of opaque and translucent material at the otolith margin suggests that the rings form annually, with the opaque ones deposited during spring-summer (Figure 3.1.2). The ages of *S. notata* ranged from 0 to 6 years for females and from 0 to 8 years for males, with a predominance of individuals in age classes 1, 2 and 3 for both sexes (Table 3.1.1). The VBGF showed higher values of the estimated rate of growth, *k*, for males than for females (Figure 3.1.3).

3.1.3.2 Biological parameters and indexes

The length of the specimens sampled ranged from 4 to 17 cm TL, with a mode at 11 cm TL (Figure 3.1.4). From the 947 individuals sexed, 471 were females and 476 males. Females predominated in the 7, 8 and 9 cm TL classes (Chi-square= 5.6, 4.1 and 12.9 respectively, and $p < 0.05$), while all individuals of 17 cm TL were males. Both sexes were equally represented in the rest of the size classes. The sex-ratio did not show significant deviations from 1:1 for the whole population (Chi-square= 0.1, p= 0.8) or throughout the year (Chi-square= 2.1, 0.2, 0.9, and 0.1 for autumn, winter, spring and summer respectively, $p > 0.2$ in all cases).

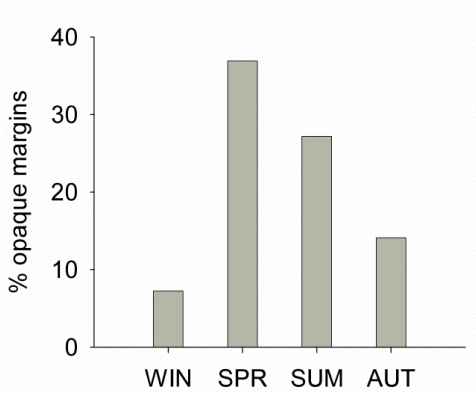


Figure 3.1.2. Seasonal variation of the percentage of opaque rings at the edge of otoliths of S. notata. WIN, winter; SPR, spring; SUM, summer; AUT, autumn.

Table 3.1.1. Age length key of *S. notata*. TL: total length; Std: standard deviation; n: number of individuals.

TL (cm)	Age (years)								
	0	1	2	3	4	5	6	7	8
Females									
4-5	1								
5-6	1								
6-7	4								
7-8	8	10							
8-9	16	20	7						
9-10	8	50	24	3					
10-11	1	38	31	11					
11-12		9	45	22	1				
12-13		1	22	46	5				
13-14			4	25	10				
14-15				10	14	2	1		
15-16				3	4	5	3		
16-17						4	2		
n	39	128	133	120	34	11	6		
Mean	8.1	9.5	10.9	12.4	13.9	15.4	15.5		
Std	1.2	1.0	1.2	1.2	1.0	0.8	0.8		
Males									
5-6	2								
6-7	5	1							
7-8	5	1							
8-9	6	17							
9-10	4	32	10						
10-11		51	31	4					
11-12		15	71	5					
12-13		1	32	40	4				
13-14			3	24	19	1			
14-15			2	16	20	6			
15-16				4	11	10	3		
16-17				1		5	4	1	
17-18					1	3	2	2	1
n	22	118	149	94	55	25	9	3	1
Mean	7.7	10.0	11.4	13.0	14.2	15.5	16.4	17.0	17.0
Std	1.3	1.0	0.9	1.1	1.0	1.1	0.7	0.9	

Mean seasonal values of GSI were significantly different for females ($F_{3, 467}$= 124.10, p< 0.001) and males ($F_{3, 473}$= 20.59, p< 0.001). The maximum mean GSI values were recorded in summer (Figure 3.1.5). August and July were the months in which the highest GSI values were recorded for females (5.70%) and males (0.59%) respectively. The first mature females and active males appeared in June and May respectively, whereas the first post-maturity females appeared in July. L_{50} was slightly higher for males (9.2 cm TL) than for females (8.8 cm TL). For both sexes L_{50} was estimated at 9.2 cm TL.

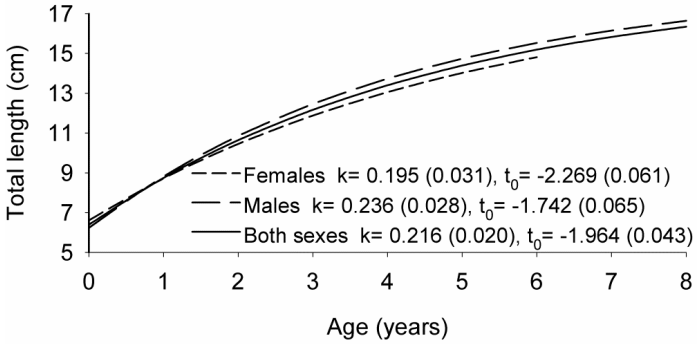


Figure 3.1.3. Von Bertalanffy growth curves and parameters determined from the interpretation of otolith rings of *S. notata*. *k* is in years^{-1}. L_∞ was set to 17.9 cm, the maximum length observed. The coefficient of variation of the estimates is shown between brackets.

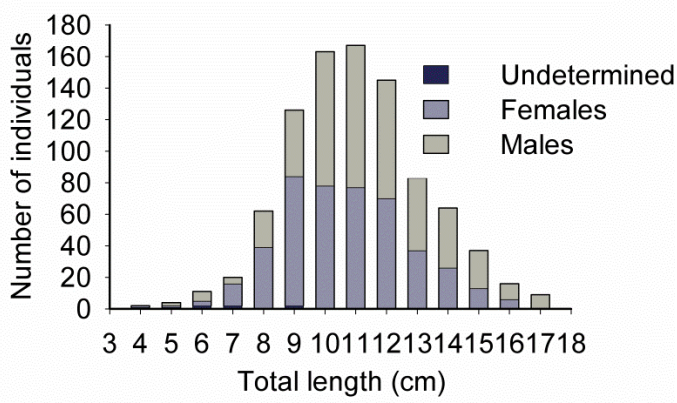


Figure 3.1.4. Length frequency distribution of the sampled individuals of *S. notata*.

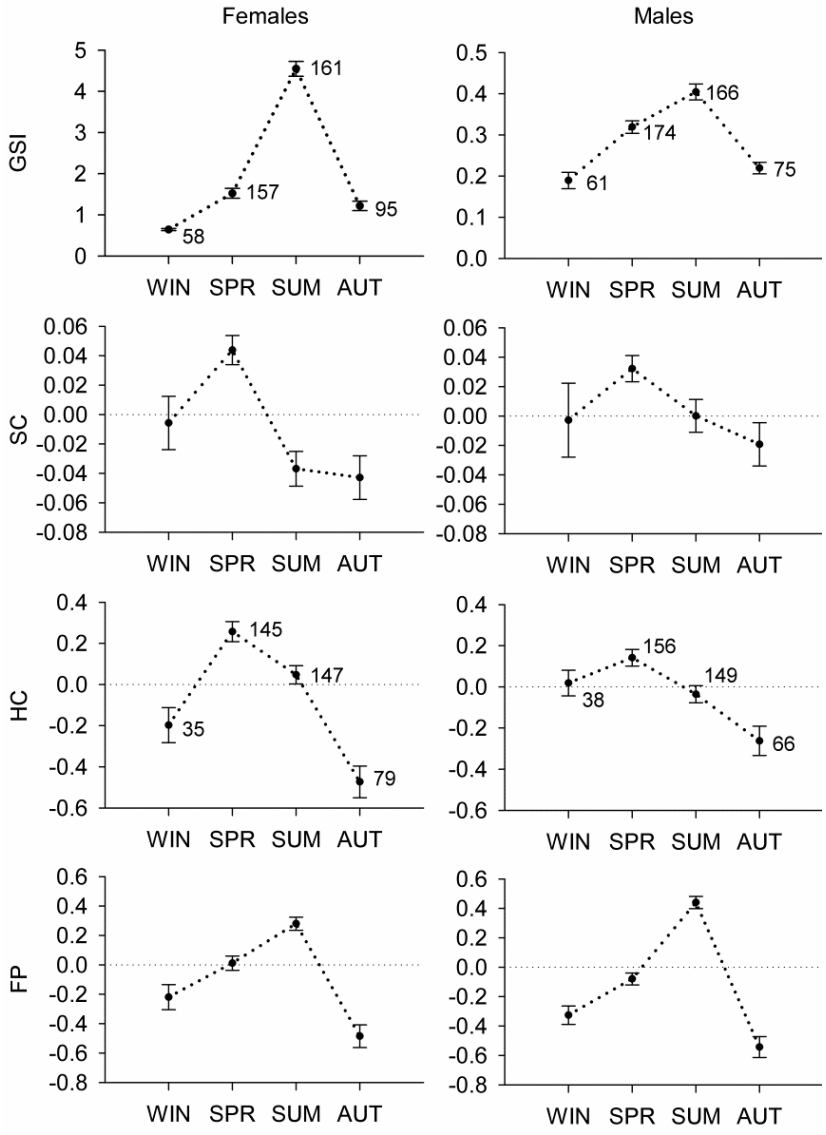


Figure 3.1.5. Seasonal variation (with its standard error) of the gonadosomatic index (GSI), somatic condition (SC), hepatic condition (HC) and feeding potential (FP), of males and females of *S. notata*. For GSI, SC and FP the number of individuals sampled per season was the same and is indicated in the plots for GSI. For HC numbers were different due to the loss of damaged livers and are also indicated. WIN: winter; SPR: spring; SUM: summer; AUT: autumn.

The length-weight relationship parameters are summarised in Table 3.1.2. When data were log-transformed, all the linear regressions calculated were significant ($p< 0.0001$). The growth in weight was allometrically positive, both for the total and eviscerated weights (TW-TL for females: $t= 156.43$, $p< 0.001$; TW-TL for males: $t= 147.91$, $p< 0.001$; EW-TL for all individuals: $t= 218.82$, $p< 0.001$). The evolution of SC, HC and FP throughout the year was similar for males and females (Figure 3.1.5). All these indexes showed significant differences in their mean seasonal values for females (SC: $F_{3, 467}= 11.91$, $p< 0.001$; HC: $F_{3, 402}= 28.32$, $p< 0.001$; FP: $F_{3, 467}= 22.50$, $p< 0.001$) and males (SC: $F_{3, 473}= 3.29$, $p< 0.05$; HC: $F_{3, 405}= 10.09$, $p< 0.001$; FP: $F_{3, 467}= 20.12$, $p< 0.001$). The maximum and minimum values of SC and HC were estimated in spring and autumn respectively, while FP reached its maximum in summer and minimum in autumn. Table 3.1.2 also shows a summary of the length-weight relationships calculated for mature females and used to compute their condition indexes. The analysis of the relationship between RC and the condition indexes SC, HC and FP showed no significant correlation in any case ($F_{1, 80}= 1.30$, $R^2= 0.016$, for RC-SC; $F_{1, 76}= 0.78$, $R^2= 0.010$, for RC-HC; and $F_{1, 80}= 0.01$, $R^2= 0.0001$, for RC-FP).

Table 3.1.2. Parameters of the length-weight relationships of *S. notata*. TW: total weight; TL: total length; EW: eviscerated weight; LW: liver weight; DW: digestive tract weight; GW: gonad weight; F: females; M: males; n: number of individuals; *a*: intercept; *b*: allometric constant. The results of the ANCOVA analysis testing for differences between sexes for each particular log-transformed length-weight relationship are also shown (d.f.: degrees of freedom; the parameter of the linear regression for which differences were found are indicated between parentheses (I: intercept and S: slope); **: $p< 0.01$ and ***: $p< 0.001$). The parameters for the whole population are presented if there are not significant differences between sexes.

Season	Relation	Sex	n	b	a	R^2	d.f.	F
All seasons	TW-TL	F	471	3.1368	0.01420	0.98	1, 944 (I)	9.28**
	TW-TL	M	476	3.0850	0.01580	0.98		
	EW-TL	All individuals	947	3.1625	0.01190	0.98	1, 944	3.47
	LW-TL	F	406	4.1219	0.00002	0.63	1, 811 (S)	13.81***
	LW-TL	M	409	3.5251	0.00006	0.76		
	DW-TL	F	471	2.5138	0.00440	0.66	1, 943 (S)	15.47***
	DW-TL	M	476	2.0811	0.01230	0.51		
Spring surveys	EW-TL	All individuals	207	3.1163	0.01340	0.99	1, 204 (I)	0.36
	LW-TL	F	101	4.3701	0.00002	0.93	1, 197 (S)	26.56***
	LW-TL	M	100	3.4874	0.00008	0.88		
	DW-TL	F	105	2.5067	0.00440	0.80	1, 204 (I)	9.54**
	DW-TL	M	102	2.2350	0.00760	0.77		
Autumn surveys	EW-TL	F	148	3.1107	0.01310	0.98	1, 290 (I)	32.19***
	EW-TL	M	145	3.1750	0.01170	0.99		
	LW-TL	F	144	3.4734	0.00008	0.71	1, 282 (I)	47.28***
	LW-TL	M	141	3.2418	0.00010	0.78		
	DW-TL	All individuals	290	2.5508	0.00400	0.60	1, 287	0.04
Summer	GW-TL	Mature females	82	2.8156	0.00120	0.57		
	EW-TL		82	3.0519	0.01560	0.98		
	LW-TL		78	4.1878	0.00002	0.65		
	DW-TL		82	2.2086	0.01060	0.56		

3.1.3.3 Abundance, fish condition, growth and habitat

The multiple regression model for testing the effects of depth and algal biomass on the abundance of *S. notata* was significant ($F_{2, 92}$= 14.79, p< 0.001) and explained up to 23% of the total variance. The algal biomass positively affected the abundance of *S. notata*, whereas no significant effect of depth was detected (Table 3.1.3). The bubble map showed that the highest abundances of *S. notata* were recorded off southern and south-western Mallorca and southern Menorca, where the contour map showed the highest algal biomass indexes (Figure 3.1.6).

The results obtained for SC_m and FP_m showed a similar scenario to that reported for the abundance of *S. notata*. The model used for SC_m was highly significant ($F_{2, 30}$= 25.33, p< 0.001) and explained up to 60% of the total variance. Only the algal biomass significantly affected SC_m, and depth showed no significant effect (Table 3.1.3). The highest values of SC_m were recorded off southern Mallorca and Menorca (Figure 3.1.6). The model used for FP_m was significant ($F_{2, 29}$= 6.34, p< 0.01) and explained up to 26% of the total variance. The algal biomass positively affected FP_m, but depth did not (Table 3.1.3). The highest values of FP_m were also recorded off southern Mallorca and Menorca (Figure 3.1.6). The model used for HC_m was not significant ($F_{2, 27}$= 0.54, p= 0.59), and hence neither the algal biomass nor the depth showed a significant effect on this parameter (Table 3.1.3).

Table 3.1.3. Multiple regression analysis summary. a-R^2: R^2 adjusted for the degrees of freedom; *β*: standardized regression coefficient; *: p< 0.05 and ***: p< 0.001.

Dependent variable	Explanatory variables	a-R^2	*β*	d.f	t	p
Abundance (n/km^2)	Algal biomass	0.23	0.47	92	4.72	***
	Depth		-0.04		-0.42	n.s
SC_m	Algal biomass	0.60	0.67	30	5.25	***
	Depth		-0.18		-1.53	n.s
HC_m	Algal biomass	0.03	0.22	27	1.03	n.s
	Depth		0.09		0.44	n.s
FP_m	Algal biomass	0.26	0.39	29	2.23	*
	Depth		-0.24		-1.37	n.s

A total of 118 females and 94 males, caught in the 15 samples with the highest algal biomass (ranging from 2700 to 15000 and averaging 7420±1 283 kg/km^2), were used to investigate habitat effects on the growth of *S. notata*. The results showed that the growth rate (*k*) of these individuals was higher than that obtained for all the individuals analysed in the present study (Figure 3.1.7), and that this trend was consistent for females (t_{1998}= 37.34, p< 0.001), males (t_{1998}= 21.36, p< 0.001), and both sexes together (t_{1998}= 55.81, p< 0.001).

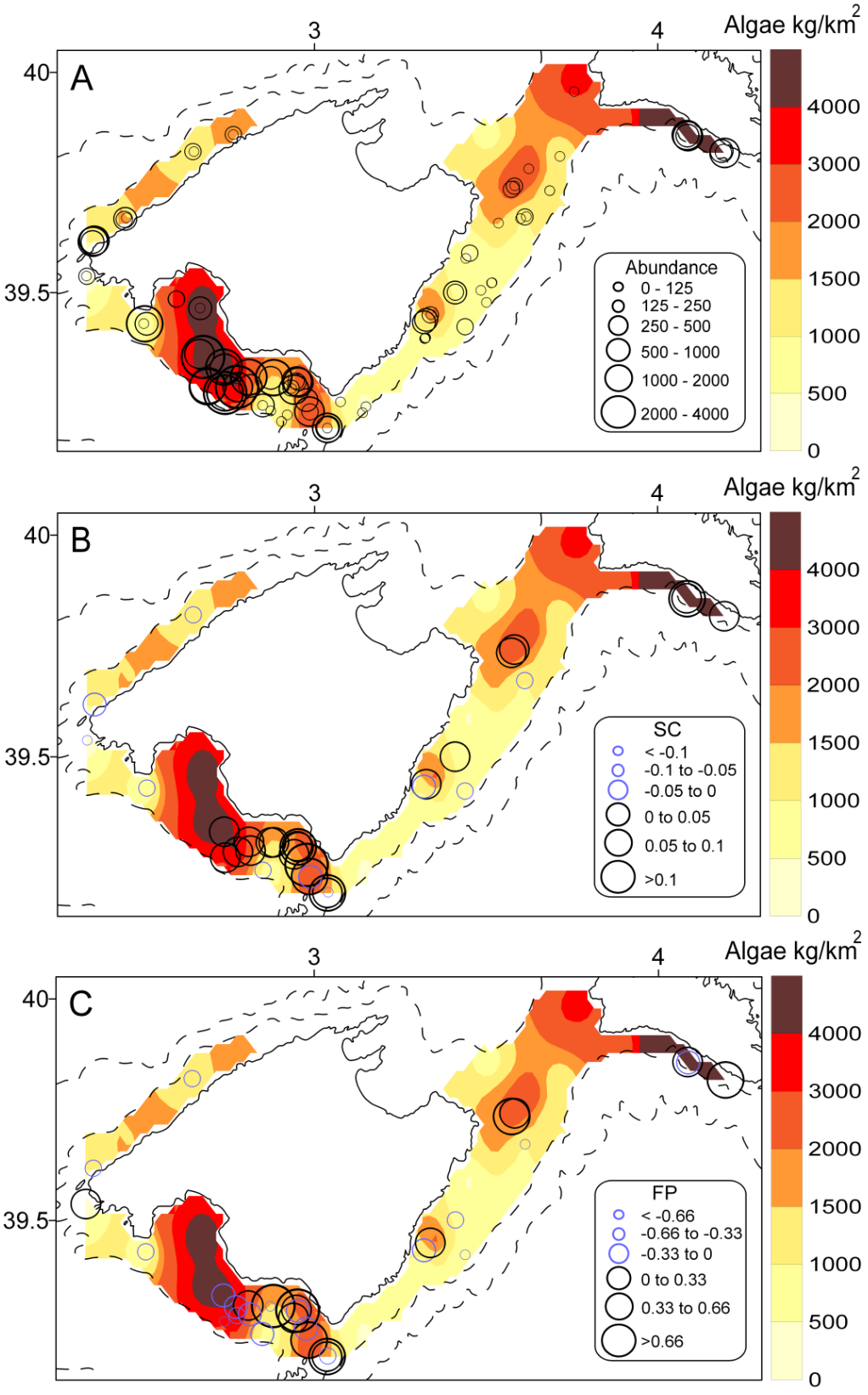


Figure 3.1.6. Bubble maps representing A) abundance (individuals/km^2), B) somatic condition (SC), and C) feeding potential (FP), plotted over the contour map showing the algal biomass.

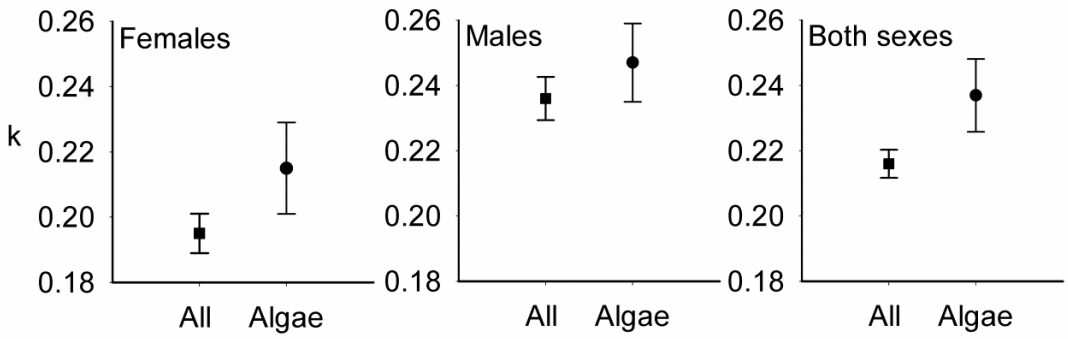


Figure 3.1.7. Growth rate values (k years^{-1}) with the standard deviation, by sex and for both sexes together, for all sampled individuals and for individuals caught in the 15 samples showing the highest algal biomass.

3.1.4 Discussion

The red scorpion fish is an important by-catch species of the commercial trawlers operating on the shallow continental shelf off the Balearic Islands, with annual landings estimated to be around 10-15 tonnes. In fact, it is the most abundant scorpaenid species at these depths, as it is much more abundant than *Scorpaena porcus* and *S. scrofa*, the two other co-generic species commonly present on the circalittoral soft bottoms of the study area (Massutí and Reñones, 2005). However, and despite the new EAF requirements for assessing and managing the highly multi-species Mediterranean bottom-trawl fisheries, this is the first study that explores the relationship between the biology of *S. notata* and the habitats where it is present.

The population studied showed no predominance of either gender, which differs from the results obtained in the adjacent Iberian coast, where females only represented 39% of the population (Muñoz et al., 2005). This could be due to the different mean size and size range of the specimens analysed in the two areas (11.5 and 7 to 16 cm standard length on the Iberian coast, and 11.4 and 4 to 17 cm total length in the Archipelago), because females predominate at smaller sizes, while the proportion of males seems to increase with size. This pattern, which has also been observed in other scorpaenid species such as *Helicolenus dactylopterus* (Massutí et al., 2000) and *Scorpaena maderensis* (La Mesa et al., 2005b), is probably due to the faster growth and longer lifespan of males compared to females. The maximum GSI values were recorded in summer for both sexes, which indicates that reproduction takes place during this season. This same trend has been previously observed by Muñoz et al. (2005) in the Iberian coast. According to the estimated L_{50} and the age-length key obtained for each sex, *S. notata* individuals seem to be prepared for reproduction when they are one year old. The species has a determinate fecundity and is considered to be a multiple spawner with a group-synchronous ovarian organization (Muñoz et al. 2005). During the reproduction period, the increase in the GSI coincides with a decrease in both SC and HC, and an increment in the FP. In the adjacent Iberian coast, individual SC did not seem to be affected by reproductive activity, although a similar trend to that found in the present study was observed between the GSI and the HC (Muñoz et al. 2005).

On the Iberian coast, the liver was considered to be an important organ for storage and the main provider of energy during gonad maturation and spawning (Muñoz et al., 2005). However, in the Balearic Islands, the supply of energy for gonad development could be linked to an energy reallocation strategy involving both somatic and liver reserves, and the food intake.

Contrary to our results, many fish species in the western Mediterranean including *S. porcus* and *S. scrofa* (Bradai and Bouain, 1990b), show the highest number of empty stomachs during the reproductive period (e.g. Macpherson, 1978; Sanz, 1985; Redón et al., 1994). Moreover, the population of *S. notata* from the Balearic Islands does not even show the seasonal patterns in its diet described off the Iberian coast (Morte et al., 2001), where high seasonal changes were detected for the proportion of empty stomachs (the lowest and highest values were found for winter-spring and summer respectively) and for the average number and weight of preys per stomach (inverse trend). The nutrient concentration present in the water seems to indirectly affect the fitness of fish populations. Some demersal species inhabiting the shelf of the Gulf of Lions, one of the most productive areas of the Mediterranean, show a higher condition than fish from areas with lower nutrient levels and productivity (Lloret et al., 2002, 2005). According to this, the red scorpion fish population of the Balearic Islands should have a low energy-storage level compared to the population from the adjacent Iberian coast. Hence, the decrease in SC and the increase in FP during the reproduction period could be physiological and trophic behaviour strategies of a population that inhabits a very oligotrophic area.

This pronounced oligotrophy should not limit the RC, as suggested by the lack of correlation between FP and the RC, SC and HC indexes for mature females, which indicates that gonad size does not depend on the amount of energy accumulated and/or on the food intake. In fact, the mean GSI values during the reproductive period on the Iberian coast and the Balearic Islands areas appear to be quite similar for both females and males (4-5% and 0.4-0.5% respectively; according to our results and Muñoz et al., 2005). Thus, the fitness and/or the food intake of the individuals analysed in the present study are sufficient for gonads to acquire a similar weight to the gonads of fish from nutrient richer areas. However, highly important variables for the reproduction success, which have not been studied here, such as gonad lipid content, fecundity or quality of eggs (Lambert et al., 2003) could display differences.

The presence of macrophytes and their detritus is an important factor that positively influences faunal diversity and secondary production of benthic communities (Dhargalkar et al., 1988; Zaitsev, 1992; Bordehore et al., 2003; Norkko et al., 2004), as well as increasing megafaunal abundance (Everett, 1994; Vetter, 1995; Vetter and Dayton, 1998). In the soft circalittoral bottoms off the Balearic Islands where the trawling fleet operate, the two widely distributed red algae facies (*Peyssonnelia* and maërl beds) provide high macrophyte biomass and an increment in the structural complexity of the benthic communities. This seems to increase the production of fish species by providing more trophic resources and shelter, especially for small individuals and small-sized species such as *S. notata* (Ordines and Massutí, 2009). A link between seagrass and the production of small scorpaenids has already been reported in Australia, where these species were found to decrease greatly in association

with seagrass loss (Edgar and Shaw, 1995). The red algae facies could be of special importance in the case of the Balearic Islands, where they show very high coverage and biomass when compared to other circalittoral, algal dominated, Mediterranean communities (Ballesteros, 1994; Bordehore et al., 2003). As an example, *Peyssonnelia* beds in the Islands, which cover large areas in south Menorca and south and southwest Mallorca (Ballesteros, 1994; Ordines and Massutí, 2009), average 2835 g dry weight/m^2 and 329% coverage, whereas the average for red algae beds in the Mediterranean northeast coast of the Iberian Peninsula is 2061 g dry weight/m^2 and 145% coverage, and only about 50 to 100 % coverage further south (Bordehore et al., 2003).

The red algae beds in the Mediterranean can be considered as ecosystem engineers because they increase the biodiversity, the structural complexity of the habitat, the local biomass and secondary production. Moreover, they can be considered as essential fish habitats, because they play a major role in the production of the main demersal resources (Ordines and Massutí, 2009). Recently, Coleman and Williams (2002) reviewed the consequences of overexploiting ecosystem engineers. These authors concluded that more attention is required for these foundation species because of the fundamental role that they play in shaping habitat and the dependent communities from microbes to predators. In the Balearic Islands the red algae beds are targeted by the bottom trawl fleet that exploits the coastal continental shelf, to the point that red algae constitute the most important group in terms of biomass discarded (Carbonell, 1998; Ordines et al., 2006). This fact is in contrast with the discards reported in the Peninsula, where algae do not even appear in the discards or are very scarce (Sánchez et al., 2004). The increased secondary benthic production in the Islands is also accompanied by an increase of the structural complexity, which may help fish to circumvent the disadvantages of living in such an oligotrophic area. The major effects of trawling on benthic communities are the loss of habitat complexity and biodiversity, and increased abundance of opportunistic species (e.g. Engel and Kvitek, 1998; Bergman and van Santbrink, 2000; McConnaughey et al., 2000; Pitcher et al., 2000; Smith et al., 2000; Hinz et al., 2009). In the western Mediterranean, trawling is considered the major anthropogenic threat to maërl beds (Barbera et al., 2003). The impact of this fishing activity includes the loss of algal coverage, substitution of Corallinaceae species by other opportunistic species more adapted to periodic disturbances, and the reduction of density and biomass of associated macrofaunal species (Bordehore et al., 2003). The wider distribution of red algae facies in the shelf bottoms off the Balearic Islands when compared to the Peninsula coast could be linked to the lower intensity of trawling in the former area, but other factor such as the hydrodynamic conditions in the area and more specifically the clarity of the waters, are also important for the distribution of these facies (Ballesteros, 1994; Ordines and Massutí, 2009).

Our results show that the abundance and the SC of *S. notata* are positively correlated with the algal biomass. However, no relation was found when the HC was considered, which suggests that physiological processes like reproduction and feeding, and their interaction with the environment, might affect the condition indexes analysed in different ways. In fact, HC has been found to be a dynamic measure that responds to short-term changes in feeding

intensity (Foster et al., 1993; Lambert and Dutil, 1997). More recently it has also been suggested that SC and HC are not equivalent measures of fish bio-energetic condition, and may follow different patterns (Pardoe et al., 2008). Some studies have attributed the spatial variability in fish condition to variations in habitat characteristics such as food availability and water temperature (Grecay and Targett, 1996; Yaragina and Marshall, 2000; Lloret et al., 2002; Rätz and Lloret, 2003; Somarakis et al., 2004). The experimental hauls used in the present analysis were carried out in a relatively narrow bathymetric range in an area where the water temperature varies little (Lopez-Jurado et al., 2008). However, a significant positive relationship between algal biomass and FP was found, which suggests that the higher SC shown by individuals inhabiting bottoms with high algal biomass is due to higher food availability. The diet of *S. notata* is based on crustaceans (up to 70 % of its food; Morte et al., 2001), a taxa that has been reported to be much more abundant in the red algae beds than in the bare sandy bottoms of the Balearic shelf (Ordines et al., 2007). Hence, these facies should constitute a high quality habitat for *S. notata*, not only because of the shelter possibilities due to the increased structural complexity, but also due to the higher abundance of its main preys, and the subsequent positive effect on condition. Similar scenarios have been already described for *Mullus barbatus* in coralligene substrata and mäerl beds (Somarakis et al., 2004; Lloret et al., 2007), pointing out that the effect of red algae facies are probably generalised to most of fish species.

Although the present work shows that the benefits for *S. notata* are positively correlated with the algal biomass in benthic communities, the results presented here are limited to bottoms subjected to the periodic removal of large amounts of algae by trawlers (Ordines et al., 2006). It is difficult to determine to what extent fish condition could be enhanced in non-exploited areas or in areas being exploited by more selective fishing gears. However, the increase in condition related to habitat seems to be large enough to have repercussions for the growth of *S. notata*. The growth rate was higher in individuals inhabiting the bottoms with the highest algal biomass than in the whole population. This relationship has also been observed in cod, for which high condition due to positive environmental effects has been reported as a factor that increases growth rates (Rätz and Lloret, 2003). The absolute fecundity of *S. notata* increases proportionally to the square of individual length (Muñoz et al., 2005). Therefore, individuals inhabiting bottoms with a high algal biomass are expected to produce more eggs than individuals of the same age inhabiting unvegetated bottoms. Hence, condition could have a positive effect on the growth and reproduction of *S. notata*, which are considered important attributes for the future success of the population (Marshall et al, 1999; Shulman and Love, 1999; Lambert and Dutil, 2000; Rätz and Lloret, 2003). Fish spend more time in habitats where they have better conditions for developing their life cycle (Minello, 1999). These habitats can be considered essential habitats for fish population success (Benaka, 1999). Although the detection of habitat effects on condition has to deal with the inherent problem of mobility of fish species, this should not be the case for *S. notata*, which has strong sedentary behaviour and a close relationship with benthic habitats (Harmelin, 1987).

The combined use of condition and feeding indexes, and growth rates could be a useful tool for identifying essential fish habitats. As occurs in other

Mediterranean fish species, the red algae bottoms appear to be an essential habitat for *S. notata*. Therefore, the presence of facies with red algae could represent an oasis of high secondary production that help particular fishery species to circumvent the oligotrophic conditions of the Mediterranean, reinforcing the necessity of urgent management measures directed to the protection of these habitats against human impacts. Precautionary measures should consider a trawling ban on these habitats as this activity is their major anthropogenic threat in the Mediterranean.

Chapter 3: Influence of benthic habitats on the condition of nekto-benthic fish

3.2 Red algae beds increase the condition of nekto-benthic fish

Abstract

The present study analyses the effect of three different benthic habitats, the maërl and *Peyssonnelia* beds, and the sandy bottoms, on the condition of two nekto-benthic fish species: *Serranus cabrilla* and *Trigloporus lastoviza*. Lipid reserves were higher in the livers of *S. cabrilla* and *T. lastoviza* from the maërl beds. Additionally, *S. cabrilla* showed higher lipid reserves in the gonads both in the maërl and *Peyssonnelia* beds. The mean weights of the liver and gonads at a given individual length revealed the same pattern as the lipids, whereas the mean eviscerated weight was higher in the maërl beds but only for *S. cabrilla*. A positive correlation was detected between the somatic condition of sexually inactive individuals and the biomass of the algal species characterizing the maërl beds for both *S. cabrilla* and *T. lastoviza*. The high habitat quality of the red algal beds off the Balearic Islands increases the condition of nekto-benthic fish. In oligotrophic areas, such as the Archipelago, these “oases” could help fish to maintain healthy populations.

Keywords: High quality habitats; benthic communities; nekto-benthic fish; biochemical condition indexes; weight at length relationship based condition measurements.

Capítol 3: Influència dels hàbitats bentònics en la condició dels peixos necto-bentònics

3.2 Els fons d'algues vermelles augmenten la condició dels peixos necto-bentònics

Resum

Aquest estudi analitza l'efecte de tres hàbitats bentònics diferents, el maërl, els fons de *Peyssonnelia* i els fons de sorra, sobre la condició de dues espècies de peixos necto-bentònics: *Serranus cabrilla* i *Trigloporus lastoviza*. Les reserves de lípids al fetge foren més elevades als individus de *S. cabrilla* i *T. lastoviza* dels fons de maërl. A més, a les gònades de *S. cabrilla* també s'hi detectaren reserves de lípids més elevades tan a fons de maërl com de *Peyssonnelia*. Els pesos mitjans del fetge i la gàonada a una determinada longitud individual mostraren el mateix patró que els lípids, mentre que el pes mitjà eviscerat fou més alt a fons de maërl, però en aquest cas només per *S. cabrilla*. Es detectà una correlació positiva entre la condició somàtica dels individus sexualment inactius i la biomassa de les algues que caracteritzen els fons de maërl tant per *S. cabrilla* com *T. lastoviza*. L'alta qualitat dels hàbitats dels fons d'algues vermelles a les Illes Balears incrementa la condició dels peixos necto-bentònics. A àrees oligotròfiques com l'Arxipèlag, aquests oasis podrien ajudar als peixos a mantenir les seves poblacions en bon estat.

Paraules clau: Hàbitats d'alta qualitat; comunitats bentòniques; peixos necto-bentònics; índexs bioquímics de condició; mesures de condició basades en relacions talla-pes.

3.2.1 Introduction

Ecosystem-based fishery management (EBFM) essentially reverses the order of management priorities in the traditional approach which focused on the target species and, instead, starts with the ecosystem (Pickitch et al., 2004). One crucial goal that should be achieved for the application of the EBFM is the identification of high quality habitats that are critical for vital population processes, the so-called essential fish habitats (Benaka, 1999). However, habitat quality cannot be measured directly and can only be studied on a comparative basis (Gilliers et al., 2004). Most efforts made to detect high quality habitats have compared the abundance and biomass of target species among different habitats, mainly focusing on recruits, juveniles and spawners (Benaka, 1999), whereas fewer studies have focused on individual biological traits.

'Fish condition' is a widely used term for referring to the overall physiological status or health of an individual (McPherson et al., 2011). Among the most important effects of poor fish condition are increased natural mortality, suppression of reproduction, late maturity and low fecundity, as well as low larval and juvenile survival (Marshall et al., 1999; Lambert and Dutil, 2000; Morgan, 2004; Rideout and Rose, 2006; Skæraasen et al., 2012). Moreover, a decrease in the productivity of fish stocks, as well as a higher vulnerability to human perturbations, has also been revealed (Dutil and Lambert, 2000).

Among the various methods used to determine fish condition, biochemical analyses are considered the most accurate ones because they supply direct information on key indicators, such as the lipid and protein reserves (Shulman and Love, 1999). However, this methodology is time-consuming, expensive, and therefore, not suitable for large numbers of individuals (Crossin and Hinch, 2005). Bioenergetic and morphometric condition indexes are based on the relative weights of the liver and gonads compared to the individual size and individual weight at length relationships, respectively, and are increasingly considered as surrogate measurements of the reserves (McPherson et al., 2011). These measurements have the advantages of being easy to collect and ready to use almost immediately. However, and more specifically, in the case of condition weight at length measurements, they must be supported by more accurate techniques, such as biochemical analyses, in order to validate that the condition is effectively measured (Davidson and Marshall, 2010; McPherson et al., 2011).

In the Mediterranean Sea circalittoral soft bottoms, two widespread benthic facies meet certain characteristic requirements that qualify them as candidates for high quality habitats, the maërl and *Peyssonnelia* beds, which are characterized by the predominance of the red algal species of the Corallinaceae and Peyssonneliaceae families, respectively (Pérès, 1985). The maërl beds are considered sensitive habitats, due to the high biodiversity they support, the low resilience of the rhodolith-forming Corallinaceae species (Donnan and Moore, 2003) and the role they play as 'ecological engineers' (Jones et al., 2000; Steller et al., 2003) by increasing the structural complexity of the soft bottoms and providing microhabitats for other species (Foster, 2001; Kamenos et al., 2004b; Barberá et al., 2012). On the other hand, the *Peyssonnelia* beds support the high benthic biomass, biodiversity, production

and structural complexity provided by the *Peyssonnelia* spp. and other associated red algal species with important erect development, such as *Phyllophora crispa* and *Osmundaria volubilis* (Ballesteros, 1994; Joher et al., 2012). Both facies are widely distributed on the soft bottoms of the continental shelf off the Balearic Islands, in the western Mediterranean (Ballesteros, 1994; Ordines and Massutí, 2009). However, their different environmental requirements separate them geographically. Maërl beds are usually found in areas of moderate to strong currents that frequently overturn the rhodoliths, preventing them from being buried and thus maintaining living algal surfaces all around (Basso, 1998; Wilson et al., 2004). On the other hand, the *Peyssonnelia* beds have been connected with open bays characterized by fine sediments, even mud, where calm periods alternate with periods of eddy forming currents (Pérès, 1985; Bordehore et al., 2003; Ordines et al., 2011). A third habitat, non-vegetated sandy bottoms, is commonly found around the Balearic Islands and exhibits the lowest benthic biomass and structural complexity (Ordines and Massutí, 2009).

Two ubiquitous and frequent nekto-benthic fish species of the continental shelf off the Balearic Islands are commonly distributed in all these three habitats: the comber (*Serranus cabrilla* Linnaeus) and the streaked gurnard (*Trigloporus lastoviza* Bonaterre). *S. cabrilla* is a serranid distributed in the Mediterranean Sea and eastern Atlantic, occupying most types of habitats such as rocks, *Posidonia oceanica* seagrass meadows and sandy and muddy bottoms, from the shoreline down to a depth of 200 m (Fischer et al., 1987). *S. cabrilla* shows an accentuated territorial behaviour and site fidelity (Schunter et al., 2011), feeding mainly on nekto-benthic crustaceans and fish (Fasola et al., 1997; Kalogirou et al., 2012). *T. lastoviza* is a triglid found in the Mediterranean and eastern Atlantic from the shoreline down to approximately 160 m. It lives on sandy and muddy bottoms, algal beds, and *Posidonia* meadows (Labropoulou and Machias, 1998; Kalogirou et al., 2010). This benthophagous species is intimately related to the bottom and uses the first three free rays of its pectoral fins as tactile organs and for locomotory assistance when moving over the sea bed in search of food, which is mainly comprised of decapod crustaceans and mysids (e.g. Labropoulou and Machias, 1998; Renous et al., 2000; Terrats et al., 2000; Boudaya et al., 2007).

In the current study, it was hypothesized that the maërl and *Peyssonnelia* beds may represent high quality habitats for the nekto-benthic fish species. To investigate this hypothesis, the present work compared the biochemical and weight at length measurements of the condition of *S. cabrilla* and *T. lastoviza* between maërl, *Peyssonnelia* beds, and sandy bottoms.

3.2.2 Material and methods

3.2.2.1 Sampling

A total of 40 bottom trawl hauls were undertaken between depths of 50 and 150 m during the 2010 and 2011 MEDITS surveys (both during the second and third weeks of June) off the Balearic Islands (Figure 3.2.1). The sampling

scheme and methodology applied during these surveys are described in detail in Bertrand et al. (2002). The hauls had a duration of 20-30 minutes with a towing speed of 2.8 knots. The set and haul of the net from the bottom, as well as its horizontal and vertical opening (on average, 16.4 and 2.8 m, respectively) were measured using the SCANMAR system.

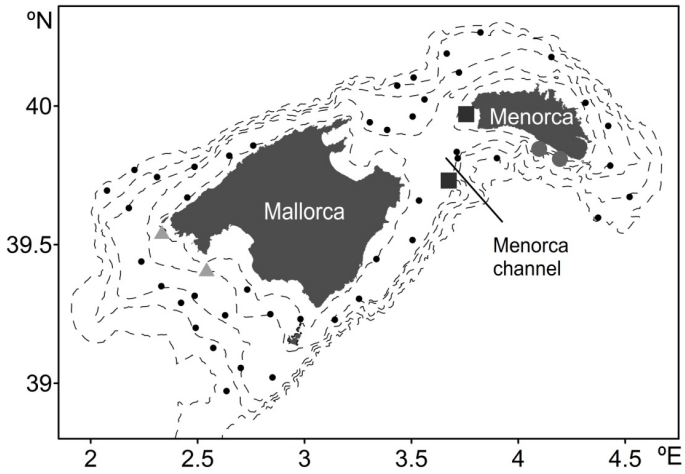


Figure 3.2.1. Map of the study area, Mallorca and Menorca (Balearic Islands, western Mediterranean), showing the initial geographical position of the stations covered during the MEDITS survey in 2010 (fully dotted). Stations selected *a priori* for each habitat are highlighted as follows: maërl (dark grey squares); *Peyssonnelia* beds (grey larger circles); sandy bottoms (light grey triangles).

Samples were sorted by species, weighed and counted. The abundance and biomass of *Serranus cabrilla* and *Trigloporus lastoviza* were determined and standardized to one square km, by using the distance covered and the horizontal opening of the net in each haul. Furthermore, total length (TL, to the nearest mm), total weight (TW, to the nearest 0.01 g), sex, and maturity stage (i.e. immature, developing, spawning, regressing and resting), estimated by visual macroscopic observation according to the scale described in Brown-Peterson et al. (2011) were recorded for a representative number of individuals of the two species in each haul.

Based on previous information about the location of extensive areas of the three habitats to be compared in the present study, maërl (Barberá et al., 2012), *Peyssonnelia* beds (Ballesteros, 1994), and sandy bottoms (Ordines and Massutí, 2009), two representative sampling stations per habitat were *a priori* selected within these areas (Figure 3.2.1). At these stations, the biological sampling of both species included recording the eviscerated, liver and gonad weights (EW, LW and GW, respectively), measured to the nearest 0.01 g, and the collection of muscle, liver and gonad tissue samples that were stored frozen at -20ºC.

3.2.2.2 Biochemical analyses

For biochemical analyses only samples from the 2010 survey were used. The reproduction period for both species has been reported to vary from area to area, depending on hydrographic and climatic conditions, although it frequently occurs during spring-summer (see Ben Jrad et al. (2010) and Ilham et al. (2010), for *T. lastoviza* and *S. cabrilla*, respectively), as is the case for the Balearic Islands (present study). To avoid variability in individual gonad development and to enable the collection of tissue samples large enough for

such analysis, only spawning females in the case of *T. lastoviza*, or spawning individuals in the case of *S. cabrilla*, which is a simultaneous hermaphrodite (García-Díaz et al., 1997), were considered. For both species, eight individuals collected from each habitat were analysed. In the case of *S. cabrilla*, the individuals ranged from 166 to 236 mm TL, whereas for *T. lastoviza*, they ranged from 153 to 225 mm TL.

The muscle, liver and gonad (100mg) were homogenized in 1ml of STE buffer (250mM sucrose, 5mM Tris-HCl and 2mM EGTA, pH 7.4) with protease inhibitors (leupeptin 10μM, pepstatin 10μM). The total protein content was measured in the homogenates using the Bradford method (Bradford, 1976). The total lipid content was determined from 1-1.5 g of tissue by applying the Folch method (Folch et al., 1957).

3.2.2.3 Condition indexes and statistical analyses

Three different types of fish condition measurements were taken based on the following:

3.2.2.3.1 Concentration of the lipids and proteins in tissues

Four indexes that relate the total amount of proteins or lipids in the liver and gonads to the EW were calculated: protein hepatosomatic index (PHSI), lipid hepatosomatic index (LHSI), protein gonadosomatic index (PGSI) and lipid gonadosomatic index (LGSI). To do so, the following equation was used: $\mathrm{I} = \mathrm{C} * \mathrm{TsW}/\mathrm{EW}$, where I is the index to be calculated, C the concentration of the lipids or proteins in the liver or gonad (mg per g of tissue), EW the eviscerated weight and TsW the total tissue weight (g).

As multiple measurements were taken from the same individuals, statistical comparisons were performed between the habitats (set as an independent variable) using a multivariate analysis of variance (MANOVA), which allows a multivariate F (Wilks' Lambda (*Λ*)) to be calculated based on the linear combination of the dependent variables, thus avoiding multiple testing. Hence, MANOVA was used to test the overall differences in: (i) the mean concentration values (dependent variables: protein and lipid concentrations in each of the tissues analysed), and (ii) the indexes (dependent variables: each of the calculated indexes). In the case of overall significant differences, analysis of variance (ANOVA) was used to test for differences between the habitats at the univariate level in order to identify which variables were responsible for the differences detected. Post-hoc comparisons were carried out using the Tukey's test. Variables were checked for the assumptions of normality and homogeneity of the variances and they were met.

3.2.2.3.2 Mean eviscerated liver and gonad weights at a given length

Similar to the statistical comparisons scheme described in the previous sub-section, the overall differences in the mean values of EW, LW and GW were compared between the habitats (independent variable) using multivariate analysis of covariance (MANCOVA). In this analysis TL was set as a covariate, as the aim was to control for the effect of this variable on the weight

measurements taken from individuals with different sizes. The analysis of covariance (ANCOVA) was used to test for differences at the univariate level. Prior to MANCOVA and ANCOVA, the homogeneity of the slopes of the relationships between TL and EW, LW and GW between the habitats, was tested by running the MANCOVA and ANCOVA models, including the interaction between the habitat and TL. Homogeneity of slopes was assumed in all cases as the interaction was not significant neither in the MANCOVA (*S. cabrilla*, $\Lambda_{6,158}$= 0.92; *T. lastoviza*, $\Lambda_{6,100}$= 0.90) nor in the ANCOVA (*S. cabrilla*, $F_{2,81}$= 0.87, $F_{2,81}$= 0.84, $F_{2,81}$= 0.07, for EW, LW and GW, respectively; T. lastoviza, $F_{2,52}$= 1.55, $F_{2,52}$= 0.43, $F_{2,52}$= 0.94, for EW, LW and GW, respectively) tests. Least squares adjusted means (i.e. the predicted value of the dependent variable after "adjusting" for the variation of the mean of the covariate (TL)) and their 95% confidence intervals were used to identify the differences detected in the ANCOVA tests. The variables and covariate were log-transformed to meet the assumption of linearity. For these analyses, in order to avoid temporal variation in maturity, only mature individuals of *S. cabrilla* and mature females of *T. lastoviza* (87 and 61 individuals, respectively) were used.

3.2.2.3.3 Somatic condition based on individual total weight

The individual somatic condition (SC) of both species was mapped for all the MEDITS stations. In order to have enough individuals, this analysis used the data on TW and TL collected during the MEDITS surveys of 2010 and 2011. Moreover, in order to reduce the variability attributed to the different stages of gonad development only inactive individuals (immature and resting) of *S. cabrilla* and males of *T. lastoviza* were used. For *T. lastoviza* all males were considered irrespective of their maturity stage, because their gonads were always small compared with the TW (<0.8%). To prevent possible temporal variations in the weight–length relationships, the SC was calculated for the individuals of each survey separately. First, the individual TW and TL were log-transformed, then the linear relationship between log(TW) and log(TL) was established by year, and then applied on an individual basis in order to obtain the predicted log(TW). Residuals or the differences between the observed and predicted log(TW) were calculated and standardized, dividing each one by the standard deviation of their predicted values. An individual that was lighter for its corresponding length, as predicted from the regression equation, would have a negative residual, and would be considered in poorer condition than one heavier for its corresponding length predicted from the regression equation, which would have a positive residual (Hayes and Shonkwiler, 2001). Once the residuals were standardized, individuals of both years were pooled for the subsequent analyses. Bubble maps representing the mean values of SC at each sampling station were created. To calculate the means, only those stations with at least four individuals were considered. These maps were superimposed onto contour maps of the standardized biomass (kg/km^2) of the characteristic algal species of each habitat: Corallinaceae species and *Peyssonnelia* spp., for the maërl and *Peyssonnelia* beds, respectively. Contours were created by applying the inverse distance to a power gridding method for the information collected in all the samples during the MEDITS surveys from 2007 to 2011. In these surveys, the algal species caught in each haul were

separated, classified and weighed. Algal weights were standardized to one square km following the same methodology described in section 2.1 for fish abundance.

Finally, multiple regression models were used to analyse the effect of the biomass of the characteristic algal species of the maërl and *Peyssonnelia* beds (set as independent variables) on the somatic condition (SC) and abundance (n/km^2) of *S. cabrilla* and *T. lastoviza* (dependent variables). Algal biomass and fish abundance were log-transformed to meet the assumption of linearity. Independent variables were checked for the absence of co-linearity before applying multiple regression (R^2= 0.09; $F_{1,27}$= 2.84; p= 0.10). The standardized regression coefficients (β), which allow the relative contribution of each independent variable to be quantified, were calculated.

3.2.3 Results

3.2.3.1 Concentration of lipids and proteins in tissues, and indexes

3.2.3.1.1 *Serranus cabrilla*

The MANOVA results showed overall significant habitat differences in the mean concentrations of lipids and proteins in the various tissues of *S. cabrilla* (Table 3.2.1). The ANOVA results showed that these differences were due to higher concentrations of proteins in the muscle, liver and gonad from the sandy bottoms than in the *Peyssonnelia* or maërl beds. In these latter habitats the individuals did not show differences, except in the case of the liver, with higher concentrations of proteins in the *Peyssonnelia* beds than in the maërl beds (Table 3.2.1 and Figure 3.2.2). No differences were detected for lipid concentrations between the habitats for any tissue (ANOVA results; Table 3.2.1 and Figure 3.2.2).

Table 3.2.1. Multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) comparing the mean concentrations of the total protein and lipid, as mg per g of tissue, in the muscle, liver and gonads of mature females of *Serranus cabrilla* and *Trigloporus lastoviza* between the maërl (M) and *Peyssonnelia* (P) beds, and sandy bottoms (S). Wilks' Lambda (Λ) and F were the statistics used in the MANOVA and ANOVA tests, respectively. In the case of the significant differences in the ANOVA comparisons, the results of the post-hoc Tukey's test identifying the relationships between the habitats are also presented. *: p< 0.05, **: p< 0.01, ***: p< 0.001.

S. cabrilla						
Statistics	Protein			Lipid		
	Muscle	Liver	Gonad	Muscle	Liver	Gonad
$\Lambda_{12,32}$			0.10***			
$F_{2,21}$	7.48**	21.86***	9.39**	3.36	3.43	1.49
Tukey's	S>(M=P)	S>P>M	S>(M=P)	--	--	--

T. lastoviza						
Statistics	Protein			Lipid		
	Muscle	Liver	Gonad	Muscle	Liver	Gonad
$\Lambda_{12,32}$			0.17***			
$F_{2,21}$	0.35	2.52	3.95*	8.01**	11.02***	1.62
Tukey's	--	--	M>S,P=M,P=S	(M=S)>P	M>(P=S)	--

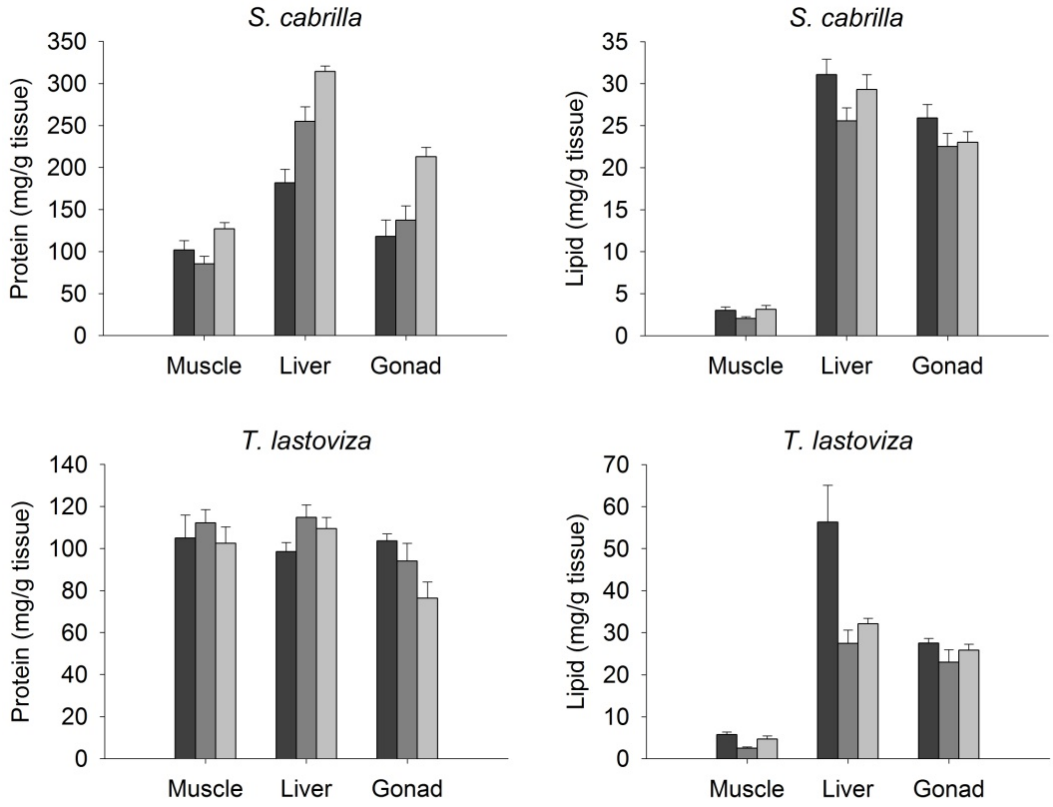


Figure 3.2.2. Histogram plots representing the mean values and standard error of the protein and lipid concentrations in the muscle, liver and gonad of the mature females of *Serranus cabrilla* and *Trigloporus lastoviza* by habitat. Maërl (dark grey); *Peyssonnelia* beds (grey); sandy bottoms (light grey).

Overall, significant between-habitat differences were detected for the mean values of the four indexes calculated (MANOVA results; Table 3.2.2). ANOVA results showed that these differences were due to the indexes based on lipids (Table 3.2.2). The LHSI was higher in the individuals over the maërl beds than over the *Peyssonnelia* beds and sandy bottoms, the latter two habitats showing similar values. However, the LGSI was higher in the maërl and *Peyssonnelia* beds (both habitats showing similar values) than on the sandy bottoms (ANOVA results; Table 3.2.2 and Figure 3.2.3).

3.2.3.1.2 *Trigloporus lastoviza*

The MANOVA results showed significant habitat differences in the overall mean concentrations of proteins and lipids in the various tissues of *T. lastoviza* (Table 3.2.1). The concentrations of proteins in the muscle and liver did not differ significantly between habitats (ANOVA results; Table 3.2.1 and Figure 3.2.2). Significant differences appeared only in the case of the gonads, with the individuals living on the maërl beds showing the highest concentrations, followed by those on the *Peyssonnelia* beds and sandy bottoms, which recorded the lowest concentrations. However, the post-hoc test only detected significant differences between maërl beds and sandy bottoms, whereas *Peyssonnelia* beds did not show differences neither with maërl beds nor with sandy bottoms (ANOVA results; Table 3.2.1 and Figure 3.2.2). The lipid

concentration in the muscle of *T. lastoviza* living on maërl beds and sandy bottoms was similar, and both habitats showed higher values than in the *Peyssonnelia* beds (ANOVA results; Table 3.2.1 and Figure 3.2.2). A higher concentration of the lipids in the liver was detected in maërl beds than in *Peyssonnelia* beds and sandy bottoms, the latter two habitats showing similar values. The lipid concentration in the gonads did not show significant differences between the habitats (ANOVA results; Table 3.2.1 and Figure 3.2.2).

Overall, significant between-habitat differences were detected for the mean values of the four indexes for *T. lastoviza* (MANOVA results; Table 3.2.2). ANOVA results showed that these differences were due to the LHSI, the only index that displayed significant differences, with higher values in the maërl beds than in the *Peyssonnelia* beds and sandy bottoms, the latter two habitats showing similar values (Table 3.2.2 and Figure 3.2.3).

Table 3.2.2. Results of the multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) comparing the mean values of protein hepatosomatic (PHSI) and protein gonadosomatic (PGSI) indexes and lipid hepatosomatic (LHSI) and lipid gonadosomatic (LGSI) indexes of the mature females of *Serranus cabrilla* and *Trigloporus lastoviza* between the maërl (M), *Peyssonnelia* beds (P) and sandy bottoms (S). Wilks' Lambda (Λ) and F were the statistics used in the MANOVA and ANOVA tests, respectively. In the case of significant differences in the ANOVA comparisons, the results of the post-hoc Tukey's test identifying the relationship between the habitats are also presented. *: p< 0.05, **: p< 0.01, ***: p< 0.001

S. cabrilla				
Statistics	PHSI	PGSI	LHSI	LGSI
$\Lambda_{8,36}$		0.24***		
$F_{2,21}$	0.88	0.38	5.95**	4.80*
Tukey's	--	--	M>(P=S)	(M=P)>S

T. lastoviza				
Statistics	PHSI	PGSI	LHSI	LGSI
$\Lambda_{8,36}$		0.25***		
$F_{2,21}$	0.34	1.02	16.66***	0.93
Tukey's	--	--	M>(P=S)	--

3.2.3.2. Mean eviscerated, liver and gonad weights at a given length

Overall significant between-habitat differences were detected for the mean values of EW, LW and GW for both *S. cabrilla* and *T. lastoviza* (MANCOVA results; Table 3.2.3). The individuals of *S. cabrilla* living on maërl beds presented higher values of EW and LW than those living on the *Peyssonnelia* beds or sandy bottoms, which displayed similar values (ANCOVA results; Table 3.2.3 and Figure 3.2.4). The GW was similar between the maërl and *Peyssonnelia* beds, but higher than on the sandy bottoms (ANCOVA results; Table 3.2.3 and Figure 3.2.4). In the case of *T. lastoviza*, only the LW showed significant differences between the habitats, recording higher values on the maërl beds than on the *Peyssonnelia* beds and sandy bottoms, the latter two habitats presenting similar values (ANCOVA results; Table 3.2.3 and Figure 3.2.4).

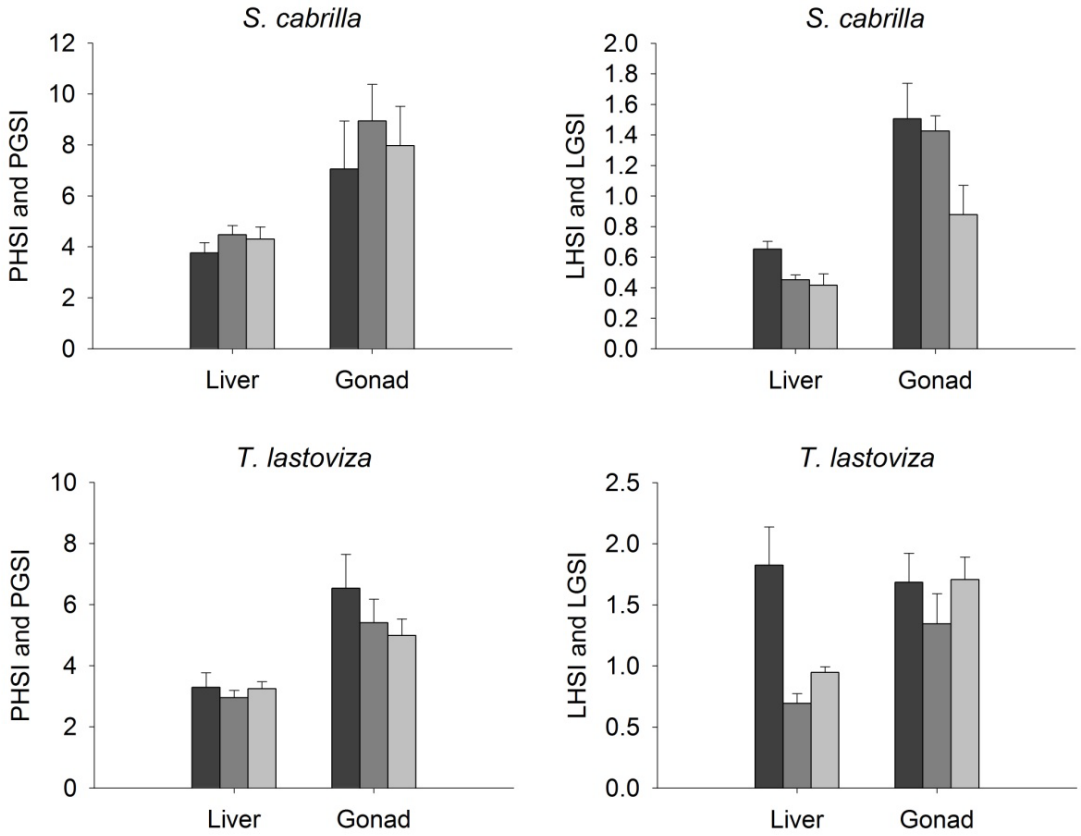


Figure 3.2.3. Histogram plots representing the mean values and standard error of the protein hepatosomatic (PHSI, in mg of protein/g EW), protein gonadosomatic (PGSI, in mg of protein/g EW), lipid hepatosomatic (LHSI, in mg of lipid/g EW) and lipid gonadosomatic (LGSI, in mg of lipid/g EW) indexes of the mature females of *Serranus cabrilla* and *Trigloporus lastoviza* by habitat. Maërl (dark grey); *Peyssonnelia* beds (grey); sandy bottoms (light grey).

Table 3.2.3. Results of the multivariate analysis of covariance (MANCOVA) and analysis of covariance (ANCOVA), comparing the mean values of the eviscerated weight (EW), liver weight (LW) and gonad weight (GW) of the mature females of *Serranus cabrilla* and *Trigloporus lastoviza*, between the maërl (M), *Peyssonnelia* beds (P) and sandy bottoms (S), while controlling for the effect of total length (TL, covariate). Wilks' Lambda (Λ) and F were the statistics used in the MANCOVA and ANCOVA tests, respectively. In the case of significant differences in the ANCOVA comparisons, the relationships between the habitats are identified using the 95% confidence intervals (95% CI) at the mean TL of each species (20 and 18.7 cm for *S. cabrilla* and *T. lastoviza*, respectively). *: p< 0.05, **: p< 0.01, ***: p< 0.001.

S. cabrilla			
Statistics	EW	LW	GW
$\Lambda_{6,162}$		0.63***	
$F_{2,83}$	10.26***	11.84***	6.33**
95% CI	M>(P=S)	M>(P=S)	(M=P)>S

T. lastoviza			
Statistics	EW	LW	GW
$\Lambda_{6,104}$		0.65***	
$F_{2,54}$	0.98	10.23***	0.07
95% CI	--	M>(P=S)	--

3.2.3.3 Somatic condition based on individual total weight

The highest values of SC for both *S. cabrilla* and *T. lastoviza* were found in the maërl beds of the Menorca Channel (Figure 3.2.5). Some positive values also appeared in the *Peyssonnelia* beds off southern Menorca and south-eastern Mallorca, particularly for *S. cabrilla* (Figure 3.2.5). *Trigloporus lastoviza* also showed a high positive value of SC in the maërl beds off southern Mallorca, and positive but low values in the maërl beds and sandy bottoms off north-western and western Mallorca, respectively. The SC values of *T. lastoviza* were always negative in the presence of the *Peyssonnelia* beds (Figure 3.2.5). The individuals of both species collected below a depth of 100 m, where the algae were absent and sandy bottoms predominated, showed negative mean values of the SC in all stations (Figure 3.2.5).

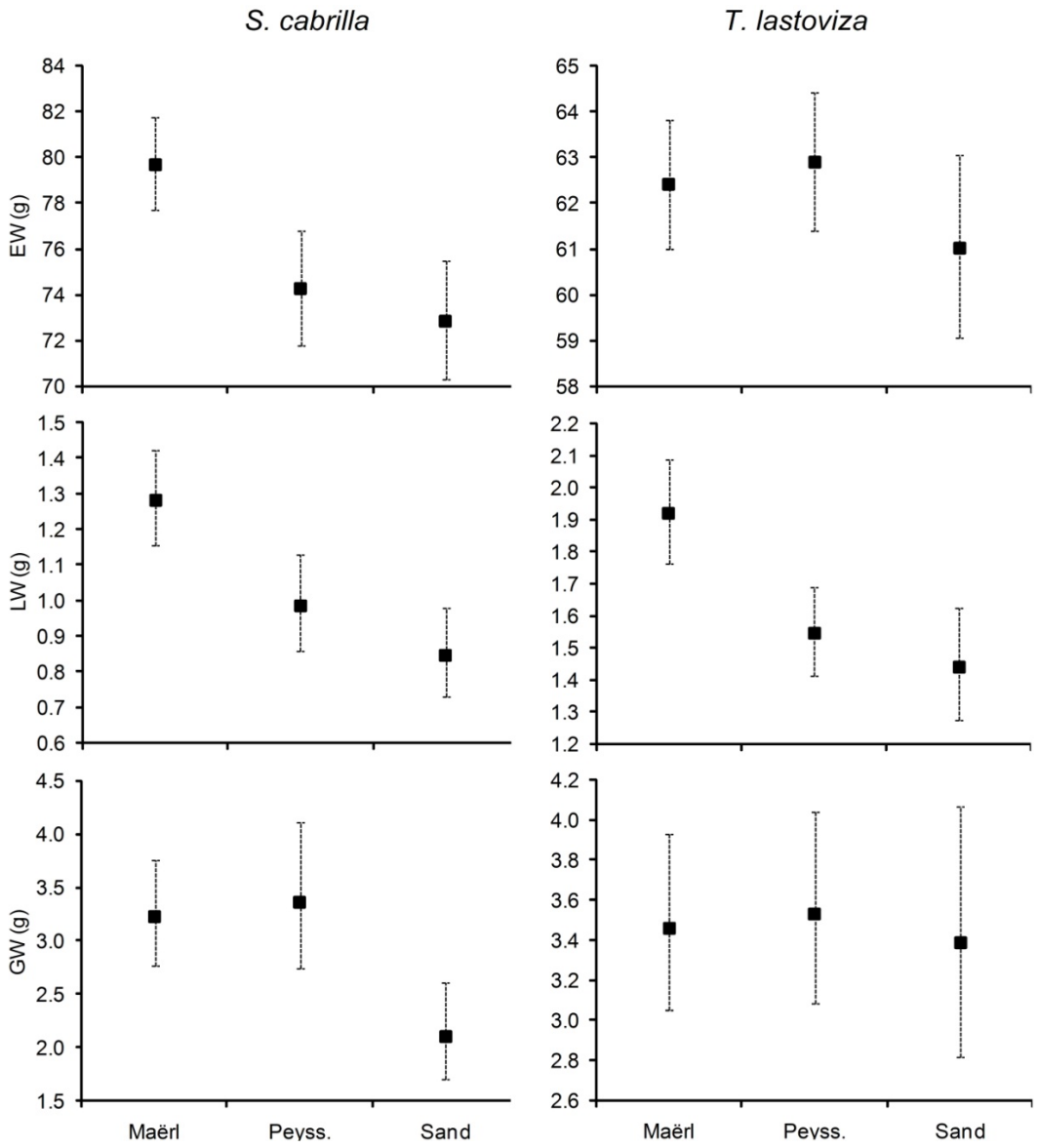


Figure 3.2.4. Estimated mean values (squares) and 95% confidence intervals (dotted lines) of the eviscerated weight (EW), liver weight (LW) and gonad weight (GW) at the mean TL, 20 and 18.7 cm, of the mature females of *Serranus cabrilla* and *Trigloporus lastoviza*, respectively.

The SC of both *S. cabrilla* and *T. lastoviza* showed a significant positive correlation with the biomass of the Corallinaceae species (Table 3.2.4). No correlation was detected between the biomass of the *Peyssonnelia* spp. and the SC of *S. cabrilla*, whereas a significantly negative correlation appeared in the case of *T. lastoviza* (Table 3.2.4). The abundance of both species showed a significant positive correlation with the biomass of the Corallinaceae species (Table 3.2.4). No correlation was detected between the biomass of *Peyssonnelia* spp. and the abundance of *S. cabrilla*, whereas a significantly positive correlation appeared in the case of *T. lastoviza* (Table 3.2.4).

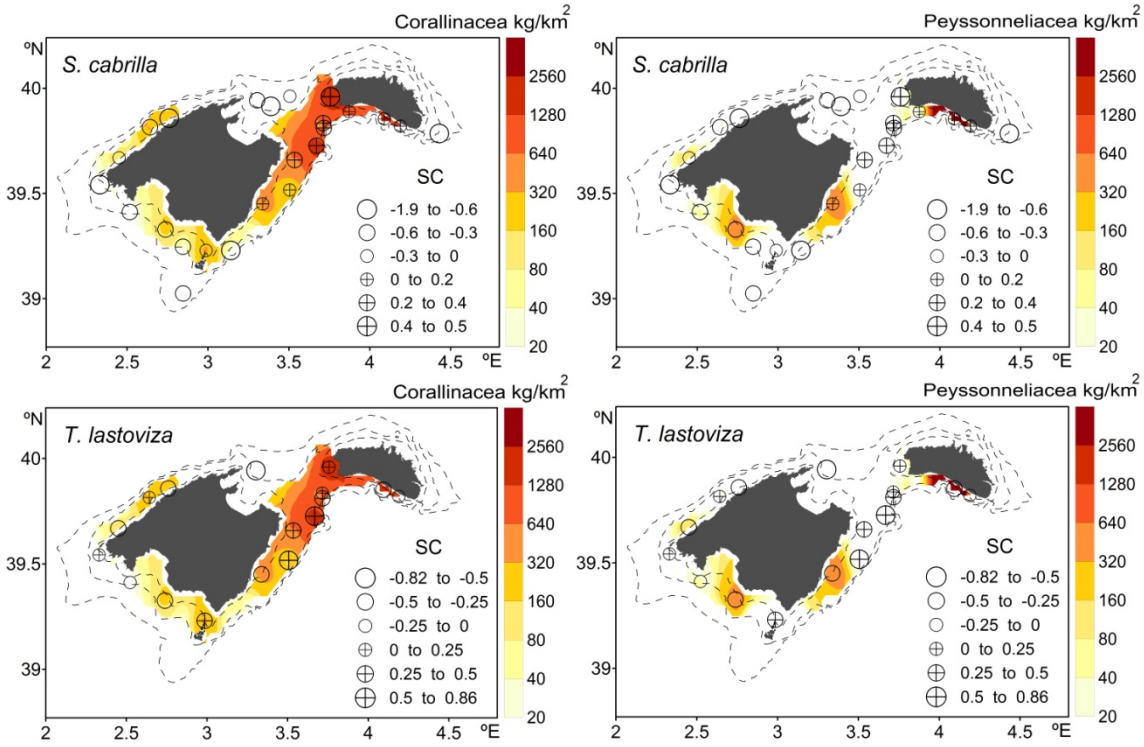


Figure 3.2.5. Bubble and contour maps showing the mean somatic condition (SC) of the sexually inactive individuals of *Serranus cabrilla* and males of *Trigloporus lastoviza* at each station, and the estimated density of the algal species characterizing the maërl (Corallinaceae) and *Peyssonnelia* beds.

3.2.4 Discussion

In the present study, the quality of three benthic habitats was compared for two nekto-benthic fish species, *Serranus cabrilla* and *Trigloporus lastoviza*, by using biochemical and weight at length measurements of fish condition.

Independently of the method used, the results were similar, except for the concentrations of lipids and proteins estimated as mg per g of tissue. However, these concentrations may not be accurate measurements of an individual's total level of reserves, because they do not take into account the size variability of tissues. A clear example of this problem is the measurement of the liver lipid reserves, which can be highly biased if only the concentrations, and not the liver size, are considered. Liver size can change markedly and affect the total

reserves available for an individual (Shulman and Love, 1999). Similarly, mature gonads may attain different sizes depending on the level of reserves, which determines the fecundity they can support (Marshall et al., 1999; Lambert and Dutil, 2000).

Table 3.2.4. The results of the multiple regression models analysing the effect of the biomass of the algal species characterizing the maërl (Corallinaceae) and *Peyssonnelia* beds on the somatic condition (SC) and abundance (n/km^2) of the sexually inactive individuals of *Serranus cabrilla* and the males of *Trigloporus lastoviza*. The F-test and t-test were used for testing the significance of the overall fit and individual explanatory variables (Expl. var.), respectively. d.f.: degrees of freedom; β: standardized regression coefficients; a-R^2: R^2 adjusted for the degrees of freedom. *: p< 0.05, **: p< 0.01, ***: p< 0.001.

S. cabrilla						
Variable	Expl. var.	d.f.	F	a-R^2	β	t
SC	Corallinaceae	2,21	9.30**	0.42	0.74	3.92***
	Peyssonnelia spp.				-0.12	-0.63
Abundance	Corallinaceae	2,26	18.41***	0.55	0.61	4.27***
	Peyssonnelia spp.				0.27	1.90

T. lastoviza						
Variable	Expl. var.	d.f.	F	a-R^2	β	t
SC	Corallinaceae	2,17	5.06*	0.30	0.42	2.13*
	Peyssonnelia spp.				-0.56	-2.81*
Abundance	Corallinaceae	2,26	11.58***	0.43	0.40	2.50*
	Peyssonnelia spp.				0.41	2.53*

For the two species analysed, both the biochemical and the weight at length condition indexes indicated that the maërl and *Peyssonnelia* beds, in the case of *S. cabrilla*, were high quality habitats on the continental shelf off the Balearic Islands. The biochemical indexes based on proteins did not reveal differences between the habitats for either of the two species. However, those based on lipids showed higher reserves in the livers of *S. cabrilla* and *T. lastoviza* living in the maërl beds, and in the gonads of the individuals of *S. cabrilla* found on maërl and *Peyssonnelia* beds. Accordingly, both *S. cabrilla* and *T. lastoviza* individuals living in maërl beds had larger livers. In addition, individuals of *S. cabrilla* living in the maërl and *Peyssonnelia* beds had larger gonads, whereas in the maërl beds, *S. cabrilla* also showed larger carcasses (i.e. eviscerated weights). The results obtained for the eviscerated weight of *S. cabrilla* must be considered with caution, because the muscle of the individuals of this species living on the sandy bottoms showed the highest concentration of proteins. Nevertheless, *S. cabrilla* did not show differences between habitats for the concentration of lipids in the muscle. Thus, individuals living in the maërl beds should have had a higher amount of lipids at a given length, as their carcasses (and hence muscle tissue) were larger than those of the individuals inhabiting the *Peyssonnelia* beds and sandy bottoms.

For most fish species, spawning is the crucial point around which most of the metabolic processes revolve (Shulman and Love, 1999). The development of the ovaries requires an energy investment which is mainly supplied by the mobilization of the lipid reserves stored in the liver (Merayo, 1996; Marshall et al., 1999; Lloret et al., 2008; Murzina et al., 2012). It is only when these

reserves have fallen to critical levels that the fish begin breaking down the muscle proteins to use them as an energy source (Shulman and Love, 1999). This point may not have been reached in any of the three habitats studied, and so the measurements of fish condition based on the lipid reserves of the spawners seem to have been more accurate than those of the protein reserves. Spawners (i.e. individuals that have already invested the energy necessary for gonad development) of both *S. cabrilla* and *T. lastoviza* inhabiting the maërl beds showed a better condition than those in the other habitats. Moreover, *S. cabrilla* living on the maërl and *Peyssonnelia* beds developed larger gonads that contained larger amounts of lipids. Fecundity was not studied in the present study, but the results obtained suggested that *S. cabrilla* in the maërl and *Peyssonnelia* beds could produce a larger number of eggs or, alternatively, larger eggs with higher lipid reserves. Similar results were obtained for the European hake (*Merluccius merluccius* Linnaeus) in the north-western Mediterranean, where pre-spawning females with a higher amount of lipids in their livers had higher amounts of lipids in their gonads (Lloret et al., 2008). These authors suggested a possible effect of the maternal condition on the reproductive potential. The lower condition shown by *S. cabrilla* in the *Peyssonnelia* beds (i.e. the lower values of eviscerated and liver weights) did not seem to impede the production of gonads similar in size to those seen in the inhabitants of the maërl beds. On the other hand, the better condition expressed by *T. lastoviza* in the maërl beds (i.e. with higher values of liver weight) was not reflected by a larger gonad size in the individuals living in that habitat. Altogether this may indicate an important role for the energy intake through the diet and its subsequent use in gonad development. Experiments with the fresh water fish *Pomoxis annularis* (Rafinesque) showed that starved or intermediate-fed females of this species increased their ovary size depending on the liver energy stores, whereas the high-fed females could develop larger gonads at the same time as the liver size increased (Bunnell et al., 2007). Among the most important factors defining habitat quality, such as predation, temperature and water quality, food availability and type of prey are critical habitat attributes for fish condition (Shulman and Love, 1999; Levi et al., 2005; Pothoven et al., 2006; Lloret et al., 2007). In the Balearic Islands, the maërl and *Peyssonnelia* beds exhibit a higher biodiversity and biomass of benthic invertebrates than the sandy bottoms (Barberá et al., 2012). Crustaceans, which are the main prey of *S. cabrilla* and *T. lastoviza* (Fasola et al., 1997; Boudaya et al., 2007), are more abundant in red algal beds than on sandy bottoms (Ordines et al., 2007). Hence, *T. lastoviza* from the *Peyssonnelia* beds and sandy bottoms, and individuals of *S. cabrilla* from the *Peyssonnelia* beds, might be able to increase their feeding activity in order to supply enough energy for gonad development when the reserves are scarce. This apparently does not apply to *S. cabrilla* from the sandy bottoms, which developed smaller gonads.

The results discussed so far were obtained from sampling stations of each habitat, which were not intermixed throughout the study area. Hence, the specific location of each habitat prevented a clear differentiation between any habitat effects and those of merely being in different places. The use of the somatic condition (SC) index, based on individual total weight, allowed the analyses to be extended to a higher number of samples and individuals, thus leading to validation of habitat effects and generalization of the results to the

whole area. The highest SC values for both species were located on maërl beds. Accordingly, SC was positively correlated to the biomass of Corallinaceae for both species, but no correlation between SC and *Peyssonnelia* spp. was detected for *S. cabrilla* and it was negative for *T. lastoviza*. Hence, while the effect of the maërl beds was clearly positive, the influence of the *Peyssonnelia* beds was not that clear, and may only have been detectable during reproduction using more specific indexes based on gonad weight or biochemical composition.

The identification of high quality habitats that maintain the fish in a better condition is especially important for the exploited species, as poor condition may contribute towards higher vulnerability and lower productivity of the stocks (Dutil and Lambert, 2000). Both the biochemical and weight at length methods used in this current study indicated that the maërl and *Peyssonnelia* beds off the Balearic Islands were high quality habitats for the nekto-benthic species. A previous study conducted in the same area on the benthic species *Scorpaena notata* (Rafinesque) showed that the biomass of the red algae positively affected its condition and growth (Ordines et al., 2009). The present study highlighted the need for an effective protection of these habitats in the Archipelago. In the clear waters around the Balearic Islands, red algae species can grow to depths of 90 to 100m (Ballesteros, 1994), forming the facies of maërl and *Peyssonnelia* beds on the trawl fishing grounds (Massutí and Reñones, 2005). Although the maërl beds are currently protected by the European directive EC-1967/2006, and bottom trawling is prohibited on these bottoms, fishing exploitation of the *Peyssonnelia* beds remains unmanaged. In addition, both habitats are currently targeted by the bottom trawl fleet operating along the continental shelf off the Archipelago (Quetglas et al., 2012). Nevertheless, the effectiveness of enforcing the current legislation on already protected habitats or the eventual protection of other sensitive or essential habitats will largely depend upon the availability of their detailed cartography. Although this information is already being collected in some areas of the Balearic Islands (Barberá et al., 2012), it is still quite fragmented.

The Balearic Islands are considered a highly oligotrophic area in the context of the general oligotrophy of the Mediterranean (Estrada, 1996). In this situation, the protection of high quality habitats can be even more critical to fish as they may depend on these “oases” and the food resources they supply in order to maintain healthy populations. The abundance of the two species analysed here was positively correlated with the biomass of the red algal species (Corallinaceae for *S. cabrilla*, and both Corallinaceae and *Peyssonnelia* spp. for *T. lastoviza*). This trend has been observed for most of the nekto-benthic fish species on the continental shelf of the Balearic Islands (Ordines and Massutí, 2009). The loss and fragmentation of these habitats, caused by bottom trawling, could result not only in a reduction of the abundance of fish populations, but also in a decrease of their resilience due to lower levels of fish condition.

CHAPTER 4

Biology and population dynamics of by-catch fish species of the bottom trawl fishery

Adapted from: **Ordines F.**, Farriols M.T., Lleonart J., Guijarro B., Quetglas A., Massutí E. (2014). Biology and population dynamics of by-catch fish species of the bottom trawl fishery in the western Mediterranean. *Mediterranean Marine Science*, 15: 613-625. doi: 10.12681/mms.812

Abstract

The teleosts *Chelidonichthys cuculus*, *Trigloporus lastoviza*, *Serranus cabrilla* and *Trachinus draco*, are important by-catch species, in terms of both landed biomass and commercial value, from the continental shelf bottom trawl fishery off the Balearic Islands. The main biological parameters of these species were calculated from monthly biological samplings, and were used along with three-year pseudo-cohorts (2008-2010) obtained from on-board monitoring of the bottom trawl fleet, to assess their exploitation by using Virtual Population Analysis (VPA) and Yield per Recruit (Y/R) analysis. Fishery independent indicators, such as abundance and biomass, and distribution range and *Conservation Status of Fish b*, last two elaborated within the Marine Strategy Framework Directive, were calculated for the time series of data collected on these species during the MEDITS scientific surveys from 2001 to 2011. The results of the VPA and Y/R analyses showed symptoms of growth overfishing for all four species analyzed. The reductions of fishing effort required to reach the $Y/R_{F0,1}$ reference point were lower, 66-73% depending on the species, to those reported for the target species *M. merluccius* (87%), but higher than that reported for *M. surmuletus* (53%), in the study area in the period 2000-2010. The time series of fishery independent indicators did not show any trend, except for the *Conservation Status of Fish b* indicator which showed signs of recovery that may be due to the displacement of the bottom trawl fishing effort from the shelf to the slope during the last decade. The results underline the necessity of incorporating monitoring and assessment of by-catch species in fisheries management, given that their populations can show more pronounced overexploitation than target ones.

Keywords: by-catch fish species; biological parameters; fishing exploitation; fishery independent indicators; assessment.

Biologia i dinàmica poblacional d'espècies 'by-catch' de la pesquera de ròssec

Resum

Els teleostis *Chelidonichthys cuculus*, *Trigloporus lastoviza*, *Serranus cabrilla* i *Trachinus draco*, són espècies 'by-catch' importants, en termes de biomassa desembarcada i valor comercial, de la pesquera de ròssec de les Illes Balears. A partir de mostrejos biològics mensuals es varen calcular els principals paràmetres biològics d'aquestes espècies, i foren emprats junt amb pseudocohorts de tres anys (2008-2010) obtingudes a partir del monitoratge a bord de la flota de ròssec, per avaluar el seu nivell d'explotació mitjançant l'Anàlisi Virtual de Poblacions (AVP) i l'anàlisi de Rendiment per Recluta (Y/R). Indicadors independents de la pesquera, com l'abundància i biomassa, i el rang de distribució i el *Conservation Status of Fish b*, els dos darrers elaborats dins la Marine Strategy Framework Directive, foren calculats per a la sèrie històrica de dades recollides per a aquestes espècies durant les campanyes científiques MEDITS des de 2001 a 2011. Els resultats de l'AVP i l'anàlisi de Rendiment per Recluta indicaren símptomes de sobrepesca de creixement per les quatre espècies analitzades. Les reduccions de l'esforç pesquer que serien necessàries per arribar al punt de referència $Y/R_{F0,1}$ resultaren ser més baixes, 66-73%, dependent de l'espècie, que la indicada, també a les Balears, per l'espècie objectiu *M. merluccius* (87%), però més altes que la indicada per *M. surmuletus* (53%), durant el període 2000-2010. Les sèries temporals d'indicadors independents de la pesquera no presentaren cap tendència, exceptuant l'indicador *Conservation Status of Fish b*, el qual mostrà signes de recuperació que podrien ser deguts al desplaçament des de la plataforma cap al talús de l'esforç de la pesca de ròssec ocorregut durant la darrera dècada. Els resultats subratllen la necessitat d'incorporar el monitoratge i l'avaluació d'espècies 'by-catch' a la gestió pesquera, ja que les seves poblacions poden trobar-se més sobreexplotades que les de les espècies objectiu.

Paraules clau: 'by-catch' d'espècies íctiques; paràmetres biològics; explotació pesquera; indicadors independents de la pesquera; avaluació.

4.1 Introduction

A large number of studies assess the main biological parameters and population dynamics of the most important species for fisheries. Moreover, the level of exploitation and status of some target stocks is periodically assessed, and this information can be used in the management of fisheries. During the last decades, the assessment and management of fisheries has progressively changed from a single-species to an ecosystem approach (Browman and Stergiou, 2004). The sustainability of marine ecosystems and fisheries requires avoiding the degradation of ecosystems, taking into account not only the target species for fisheries, but also the other components of the ecosystem (e.g. non-target species, vulnerable species, environmental conditions and trophic webs) and elucidating habitats critical to species for vital population processes (Pickitch et al., 2004).

The Mediterranean Sea is characterized by high diversity, both at community and species level (Pérès and Picard, 1964; Fredj et al., 1992; Bianchi and Morri, 2000), which is also reflected in the catch of its fisheries. This is particularly clear for the bottom trawl, highly multi-specific (Lleonart and Maynou, 2003) and with a large amount of by-catch of both commercial and non-commercial species and discards (e.g. Stergiou et al., 1997; Moranta et al., 2000). In this area, single-species approach to fisheries has mainly been focused on the target species, but very few studies have addressed by-catch ones (e.g. Farrugio et al., 1993; Lleonart and Maynou, 2003; Moranta et al., 2008). This is probably due to both the lack of biological data, and incomplete information about fishing exploitation of these species. That is the case of the bottom trawl fishery along the continental shelf, off the Balearic Islands (western Mediterranean), between 50 and 200 m depth, whose main target species are the striped red mullet (*Mullus surmuletus*) and picarel (*Spicara smaris*), and the cephalopod common octopus (*Octopus vulgaris*) on the shallow shelf, and the European hake (*Merluccius merluccius*) on the deep shelf (Palmer et al., 2009). However, up to 67 species (57 fishes, 8 cephalopods and 2 decapod crustaceans) are commonly captured (Ordines et al., 2006). Most of these by-catch fish species, with the exception of *Trachurus* spp.*,* and large specimens of *Scorpaena* spp., *Lophius* spp., *Zeus faber* and *Lepidorhombus* spp., are sold together, in a mixed fish commercial category (MFC) known as “morralla”. This is a common practice in some areas of the Mediterranean, allowing commercialization of species, which separately would have a low commercial value or could not even be sold on the fish market.

In Mallorca (Balearic Islands; Figure 3.2.1), within the MFC, the teleost fishes *Chelidonichthys cuculus* and *Trigloporus lastoviza*, both belonging to the family Triglidae, and *Serranus cabrilla* and *Trachinus draco*, belonging to the families Serranidae and Trachinidae, respectively, are among the most important species (Ordines et al., 2006). These species are also among the most important components of the demersal assemblages present on the continental shelf, *T. lastoviza* appearing almost exclusively on the shallow shelf (<100 m), *S. cabrilla* and *T. draco* having a wider bathymetric range including both the shallow and middle shelf down to 150 m, and *C. cuculus* being deeper distributed in the middle and deep shelf down to around 200 m (Massutí and Reñones, 2005). Despite their importance in demersal communities and

fisheries in the Mediterranean, these species have received relatively limited attention, with the information remaining fragmented in most cases, while very few studies cover the main traits of the life history of these species (*C. cuculus*: Colloca et al., 2003b; *S. cabrilla*: Torku-Koc et al., 2004; İlhan et al., 2010).

Within the ecosystem approach to fisheries assessment and management, habitats are receiving increasing attention and the identification and mapping of some sensitive and essential fish habitats is now a mandate of the European Commission (Council Regulation EC 1967/2006). However, there is still poor knowledge on an important aspect of multi-specific fisheries, such as the level of exploitation of by-catch species. The present work aims to describe the main biological parameters of *C. cuculus, T. lastoviza, S. cabrilla* and *T. draco* and to assess the population dynamics and the exploitation level of these important by-catch species in the bottom trawl fishery off the Balearic Islands. The results obtained will contribute to the improvement of the biological knowledge of poorly studied fish species in the western Mediterranean and to the assessment of the bottom trawl fishery developed in the area.

4.2 Material and methods

4.2.1 Sampling of the commercial fishery

The information on landings of the bottom trawl fleet operating off Mallorca was obtained from the official statistics facilitated by OP MALLORCAMAR, the fisheries producers of Mallorca. These data consist of daily sale bills, with the biomass and price of each commercial category by boat.

During 2008-2010, sampling of commercial catches was conducted monthly on board commercial bottom trawlers from Alcúdia, Palma and Santanyí, three of the most important fishing ports in Mallorca (Figure 4.1), whose fleet operates on the continental shelf. This sampling was developed within the Data Collection Framework (Commission Regulation EC N^{o} 1639/2001) and included information on the composition of the MFC (weight and number of individuals of each species gathered in this category), discards and landings, and the length frequency distribution of representative samples of *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco* (Table 4.1).

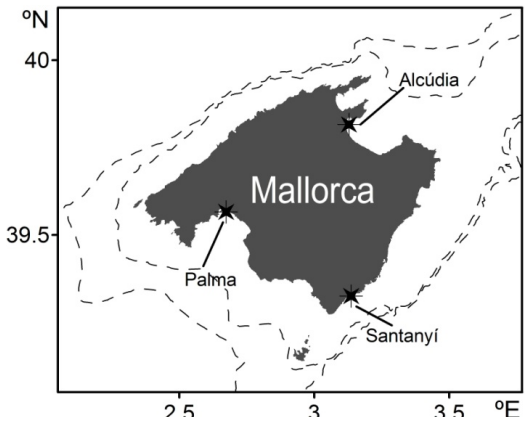


Figure 4.1. Map of the study area showing the three harbours considered: Alcúdia, Palma and Santanyí.

During 2001-2002, monthly samplings of the studied species were carried out, from commercial landings, at the laboratory, including individual total length (TL, to the nearest mm), total weight (TW), eviscerated weight (EW) and gonad weight (GW). All these weights were measured to the nearest 0.01 g. Sex and maturity were also determined from the macroscopic observation of the gonads, according to the maturity scale described in Brown-Peterson et al. (2011), and sagittal otoliths were removed (Table 4.1).

Table 4.1. Number of individuals sampled by data source and species.

Source	Sampling	*C. cuculus*	*T. lastoviza*	*S. cabrilla*	*T. draco*
On board (2008-10)	Length	3041	1134	2147	3485
Landings (2001-02)	Biological	261	542	553	595
	Otoliths	227	436	338	553
Surveys (2001-11)	Length	12718	4341	9561	7257
	Biological	1899	886	1985	1459
	Otoliths	646	663	743	652

4.2.2 Sampling during scientific surveys

Data and samples were also collected from the MEDITS bottom trawl surveys, carried out annually since 2001 around Mallorca-Menorca during May-July, between 50 and 800 m depth. The sampling scheme, stratified considering four depth strata (50-100, 101-200, 201-500 and 501-800 m), and the gear used in these surveys were the same as those used throughout the Mediterranean in bottom trawl surveys since 1994 (Bertrand et al., 2002). Hauls were conducted during daylight hours, with an effective duration of 20-60 minutes (net in contact with the sea bed), depending on the depth. The average towing speed was 2.8 knots. The arrival and departure of the net at/from the bottom, as well as its horizontal and vertical openings (on average, 16.4 and 2.8 m, respectively) were measured using a SCANMAR system.

A total of 467 experimental hauls were analyzed. In each sample, abundance, biomass and length frequency of the studied species were determined. Biological samples were also taken and saggital otoliths were removed to complete the biological data obtained from the sampling of the commercial landings (Table 4.1). Abundance and biomass were standardized to one square km, using the horizontal opening of the net and the distance covered in each haul.

4.2.3 Biological parameters

Length-weight relationships were established by power regression ($\mathrm{TW} = \mathrm{a} * \mathrm{TL}^{\mathrm{b}}$) for sexes combined and using all the biological samplings available from both landings and surveys (Table 4.1). The reproductive period was assessed from the seasonal evolution of the gonadosomatic index (GSI) of females sampled within the monthly biological sampling carried out on samples of landings in the years 2001 and 2002, and females collected during the scientific surveys corresponding to that period (Table 4.1). The GSI was calculated as follows: $\mathrm{GSI} = 100 * \mathrm{GW}/\mathrm{EW}$. The proportion of mature individuals (PL) for a given size class L during the reproductive period was used to

calculate the vector of maturity by length class and the length at first maturity (L_{50} or length at which 50% of the individuals are mature) for sexes combined from the logistic curve $\mathrm{PL} = \mathrm{e}^{(a+b*L)}/(1+\mathrm{e}^{(a+b*L)})$; to do so, all the individuals sampled either from landings or scientific surveys (in case that the surveys took place during the reproductive period) were used (Table 4.1).

All the otoliths collected either from landings samples or scientific surveys were taken into account to study the growth of the species (Table 4.1). Otoliths were immersed in a 50% mixture of glycerol-alcohol and the number of translucent rings was counted by two readers with a compound microscope using reflected light, following standard techniques (Morales-Nin, 1987). Readings not coincident between readers were repeated again and not taken into account for further analyses if an agreement was not met. Marginal increment analysis was used to verify the increment periodicity of the rings (Morales-Nin, 1992). Once the rings were considered to be annual, and taking into account the date of capture, the number of rings, their formation period and the spawning season, each specimen was assigned to an age class. The von Bertalanffy growth function (VBGF) was fitted to the observed length-at-age data according to $\mathrm{L_t} = \mathrm{L_\infty}(1-\mathrm{e}^{-\mathrm{k}(\mathrm{t}-\mathrm{t_0})})$; where L_t is the total length at age t, L_∞ is the asymptotic length, k is the instantaneous growth coefficient and t_0 is the hypothetical age at which length is equal to zero.

All biological parameters were calculated using the INBIO package in R (Sampedro et al., 2005), which implements the Gauss-Newton algorithm for non-linear least squares parameter estimation, and enables the calculation of their coefficients of variation (CV) by using a bootstrap routine.

The von Bertalanffy and the length-weight relationship parameters were used to calculate a vector of natural mortality (M) by age for each species. To do so, we used the PRODBIOM methodology (Abella et al., 1997) based on the reciprocal M-at-age model proposed in Caddy (1991). This was considered a more suitable option than using a constant natural mortality due to the fact that a large part of the catches of the species analyzed were composed of individuals belonging to young age classes (see results), which are commonly subjected to higher natural mortality rates than older ones (Abella et al., 1997).

4.2.4 Population dynamics and exploitation

The data obtained during monthly sampling on board the bottom trawl fleet was used to estimate the annual length frequency distributions of catches. For each species, only the ports and depth strata where they were well represented in the catches were considered. Thus, for *C. cuculus*, the fleet from Alcúdia operating on the deep shelf (100-250 m depth) was considered; for *T. lastoviza* the fleet from Palma and Santanyí operating on the shallow shelf (50-100 m depth) was considered; and for *S. cabrilla* and *T. draco* the fleet from Alcúdia operating on the deep shelf and from Palma and Santanyí operating on the shallow shelf were considered.

For the period 2008-2010, the species biomass composition of the MFC was calculated per year, port and strata in order to obtain the percentage of each of the studied species. These proportions, along with the amount of

discards of each species, estimated from sampling on board, the annual length distributions and the total weight of landings of the MFC in Mallorca (obtained from the official statistics), were used to calculate the total annual biomass of catches by species, and the total number of individuals caught by length class. Pseudocohorts of each species were calculated as an average of the annual number of individuals caught by length class during the three-year sampling on board period. The population dynamics and exploitation of the studied species were analyzed by means of a Length Cohort Analysis (LCA), using the Virtual Population Analysis (VPA) on the mean length pseudocohorts, as implemented in the VIT software (Lleonart and Salat, 1992). This program was designed to analyze exploited marine populations, based on catch data, structured by age or size, and assuming a steady state of the population. The steady state is quite a restrictive assumption because it involves constant recruitment and mortality and a constant level of exploitation. Despite this, the analysis of length pseudocohorts has been commonly used to assess the state of Mediterranean exploited marine populations when lacking suitable historical data series allowing more standard VPA procedures based on catch-at-age data. Moreover, these approaches have frequently used mean length pseudocohorts obtained from different consecutive years (Demestre and Lleonart, 1993; Oliver, 1993; Aldebert and Recasens, 1996; Lleonart and Maynou, 2003; GFCM, 2014). Mean length pseudocohorts have also been considered to compensate for the effect of inter-annual variability in recruitment (Pallares, 1992; Aldebert and Recasens, 1996).

The fishing effort of the bottom trawl fleet in Mallorca during the period used to calculate the mean pseudocohorts was assumed to be constant. The number of boats was the same for all three years (34), with the same distribution among harbours (OP MALLORCAMAR), and no changes in the regulation of the bottom trawl fishery, and similar landings (see results).

The VPA applied to each species used a vector of M, the VBGF parameters and a terminal fishing mortality value (F_t, i.e. the value of fishing mortality for the last length class). Several values of F_t (0.1, 0.2, 0.3 and 0.4) were considered in order to investigate the sensitivity to such parameter. The maturity vector was also used to estimate the spawning stock biomass (SSB). A plus class was used when the number of individuals in one or several of the largest length classes showed a null value. Calculation of plus classes consisted in pooling the individuals of the remaining larger size classes. That was the case for *T. lastoviza* (24-26 cm), *S. cabrilla* (26-28 cm) and *T. draco* (29-33 cm).

A Y/R analysis was carried out using the vector of fishing mortality (F) obtained from VPA, the length-weight relationship parameters and the length distribution of catches.

4.2.5 Fishery independent indicators

The average stratified abundance and biomass of the studied species were calculated from MEDITS data by multiplying the average standardized abundance (individuals/km^2) and biomass (g/km^2) of each stratum by its surface and dividing it by the total surface of all strata. Taking into account that the

studied species are mostly distributed on the continental shelf, only the 50-100 m and 101-200 m sampling strata were taken into account. Trends of the stratified abundance and biomass during the time series (2001-2011) were analyzed by means of linear regression. The indicators distribution range and Conservation Status of Fish *b* (CSF*b*), elaborated within the context of the Marine Strategy Framework Directive (EU, 2008; IEO, 2012) were also calculated from MEDITS survey data.

The distribution range is based on geo-referenced presence/absence matrixes. The sampled area was divided into grids of 10x10 nautical miles. Then the percentage of grids in which the species were present, in relation to the total number of sampled grids, was calculated on an annual basis. With the objective of comparing the percentages between years, and taking into account both the random stratified sampling and changes in the number of sampled grids throughout the period analyzed, the annual percentages of appearance were standardized using $\%C_{+i} = (C_{+i}/C_t)/(C_{mi}/C_{max})$; where C_{+i} is the number of grids where the species was present in year i, C_t the total number of grids in the whole area, C_{mi} the number of sampled grids in year i and C_{max} the maximum number of grids sampled any year. The temporal trend of $\%C_{+i}$ was analyzed by means of linear regression.

The CSF*b* measures the percentage of large individuals at community level in relation to an initial reference period. To calculate this indicator, we used the stratified standardized abundances by length class, calculated in the same way as explained above for total abundance and biomass. Then, at species level, we calculated: 1) the total abundance of large individuals (length > $0.5L_\infty$); 2) the mean abundance of large individuals in the first 3 years of the MEDITS time series (2001-2003); and 3) for the successive years, the proportion represented by the abundance of large individuals of each species in relation to the mean abundance in the first three years. For any given year, the CSF*b* indicator is calculated as the geometric mean of the relative abundance of the studied species. The temporal trends of CSF*b* and proportions of large individuals in relation to the reference period at species level were analyzed by linear regression.

4.3 Results

4.3.1 Catch and composition of the MFC

During the last decade, official annual landings of the MFC averaged 143 tons, which represents up to 6 and 5% of the total landed biomass and economic value obtained by the bottom trawl fleet, respectively (Figure 4.2). The mean landings of the MFC were larger than those for the target species of the fishery, *M. surmuletus* (96 tons/year) and *M. merluccius* (82 tons/year), and barely less than that of *S. smaris* (157 tons/year), throughout the studied period. In terms of biomass, the most important species of the MFC were *S. cabrilla* (17.4%), *T. draco* (17.1%), *C. cuculus* (13.2%), *Scorpaena notata* (9.0%), *T. lastoviza* (6.5%) and *Pagellus erythrinu*s (6.2%) (Figure 4.3). Although these

main species represented about 70% of the total biomass of the MFC, the rest of it is composed of a large number of species, up to more than 50 (Figure 4.3).

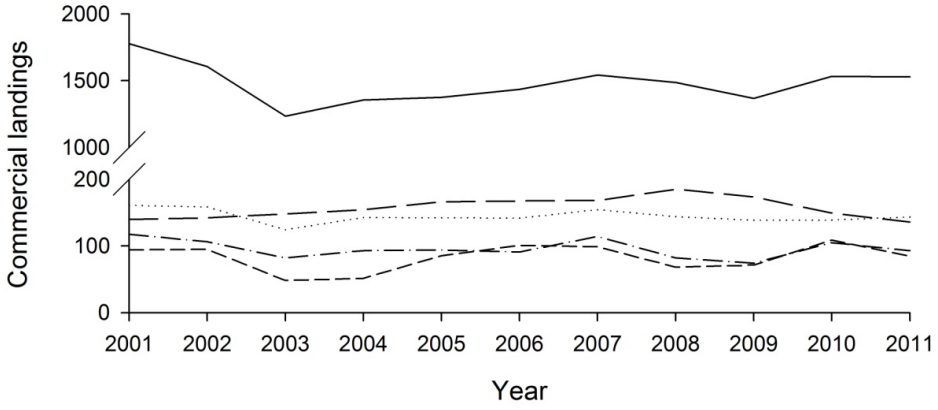


Figure 4.2. Time series of the commercial landings (tons) of the bottom-trawl fleet off Mallorca for Total landings (continuous line), *Spicara smaris* (dashed line), MFC (dotted line), *Mullus surmuletus* (dash-dotted line), and *Merluccius merluccius* (short-dashed line).

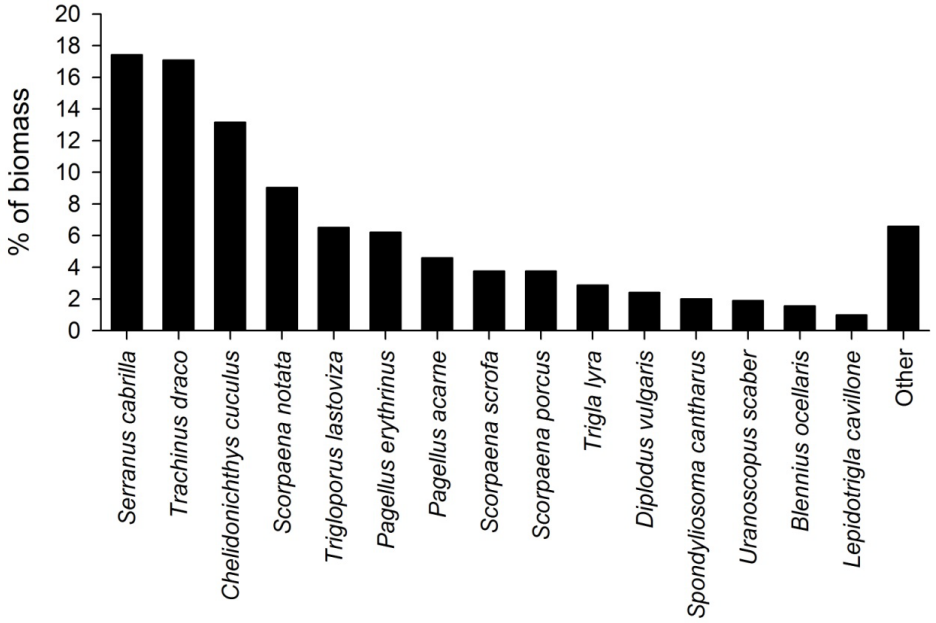


Figure 4.3. Species composition (in % of landed biomass) of the mixed fish category (MFC). "Other" are species representing less than 1%: *Trisopterus minutus*, *Zeus faber*, *Diplodus annularis*, *Trachinus radiatus*, *Helicolenus dactylopterus*, *Lepidotrigla dieuzeidei*, *Anthias anthias*, *Microchirus variegatus*, *Citharus linguatula*, *Microchirus ocellatus*, *Peristedion cataphractum*, *Callanthias ruber*, *Scorpaena elongata*, *Sparidae*, *Cepola macrophthalma*, *Phycis blennoides*, *Serranus hepatus*, *Lophius piscatorius, Phycis phycis, Scorpaena loppei, Thalassoma pavo, Gaidropsarus biscayensis*, *Coris julis*, *Solea* spp., *Serranus scriba*, *Ophidion barbatum*, *Arnoglossus thori*, *Bothus podas*, *Lophius budegassa*, *Lepidorhombus boscii*, *Scomber scombrus*, *Spicara smaris*, *Arnoglossus rueppelii*, *Synchiropus phaeton*, *Centracanthus cirrus*, *Pagellus bogaraveo*, *Merluccius merluccius*, *Arnoglossus imperialis*, *Engraulis encrasicolus*.

Table 4.2. Parameters of the length-weight relationship ($TW = a * TL^b$; TW in g and TL in cm); the von Bertalanffy growth function (VBGF; L_∞ in cm, k in year^{-1}, t_0 in years) and the maturity parameters (L_{50} in cm, L_{25}-L_{75} in cm) for the studied species and their associated coefficient of variation (CV) between brackets.

Species	Length-weight		VBGF			Maturity	
	a	*b*	L_∞	*k*	t_0	L_{50}	L_{25}-L_{75}
C. cuculus	0.005 (0.15)	3.196 (0.02)	37.6 (0.20)	0.176 (0.22)	-1.264 (0.15)	16.8 (0.01)	2.01
T. lastoviza	0.010 (0.13)	3.030 (0.01)	28.4 (0.05)	0.409 (0.12)	-0.007 (4.58)	15.5 (0.02)	4.99
S. cabrilla	0.014 (0.09)	2.903 (0.01)	38.8 (0.08)	0.173 (0.12)	-0.185 (0.32)	14.8 (0.01)	4.72
T. draco	0.005 (0.12)	3.075 (0.01)	42.3 (0.06)	0.101 (0.10)	-1.825 (0.09)	14.4 (0.05)	6.47

4.3.2 Biological parameters

The GSI along the year showed that the reproduction period occurs from January to April for *C. cuculus*, from March to June for *T. lastoviza*, from April to June for *S. cabrilla* and from June to October for *T. draco* (Fig 4.4). The species with the largest L_{50} was *C. cuculus* (16.8 cm), whereas the smallest one was that of *T. draco* (14.4 cm). The L_{50} of *S. cabrilla* and *T. lastoviza* were 14.8 and 15.5, respectively (Table 4.2).

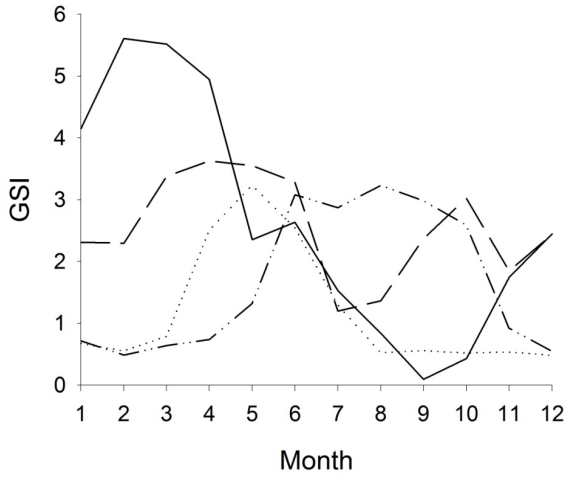


Figure 4.4. Monthly evolution of the mean gonadosomatic index (GSI) of females for the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

The length-weight relationship parameters are shown in Table 4.2. The otoliths showed the typical pattern for teleosts: alternations of translucent and opaque rings formed seasonally around an opaque nucleus. The seasonal evolution of the % of presence of opaque rings in the margin of the otoliths showed that the main deposition of this kind of rings occurs during the second quarter of the year for *C. cuculus* and *T. draco*, whereas for *T. lastoviza* and *S. cabrilla* it occurs during the last and first quarters of the year (Figure 4.5). *T. draco* showed the longest life span, with age classes ranging from 0 to 9. The rest of the species showed similar life spans ranging from 0 to 5, 0 to 4, and 0 to 6 years for *C. cuculus*, *T. lastoviza* and *S. cabrilla*, respectively. The VBGF

parameters and fitted curves are shown in Table 4.2 and Figure 4.6. The highest value of *k* corresponds to *T. lastoviza* (0.41 $year^{-1}$) and the lowest one to *T. draco* (0.10 $year^{-1}$), while the values for *C. cuculus* and *S. cabrilla* were similar (0.17 and 0.18 $year^{-1}$, respectively).

4.3.3 Population dynamics and exploitation

The pseudocohorts of all the studied species showed similar ranges of total length: 11-26, 6-26, 8-28 and 9-33 cm for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively (Figure 4.7). The modes were located at 16 cm for *C. cuculus* and at 17 cm for the rest of species. An important proportion of the catches of the four species analyzed were composed of young individuals. In this sense, 69 and 68% of the catches of *C. cuculus* and *T. lastoviza*, respectively, consisted of individuals with a TL equal or smaller to that corresponding to 2 years old. In the case of *S. cabrilla* and *T. draco*, 43 and 48% of the catches, respectively, consisted of 3 years old or younger individuals (Figure 4.6 and Figure 4.7). The *M* vectors used as inputs for the VPA are shown in Figure 4.8. For the most abundant size classes of the species analyzed, the values of *M* varied between 0.13 for both *C. cuculus* and *T. draco*, and 0.21 and 0.29 for *T. lastoviza* and *S. cabrilla*, respectively.

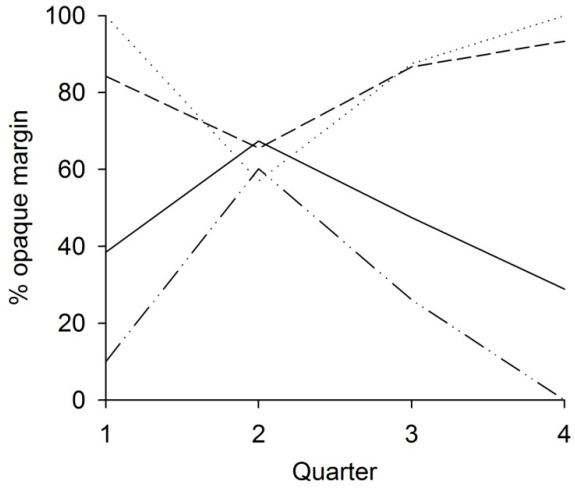


Figure 4.5. Quarterly evolution of the % of presence of opaque rings in the margin of the otoliths of the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

VPA results showed that the mean length and age of the catches were above the critical length and age of the estimated population at sea for all species (i.e. the length and age at which the population shows its maximum biomass, respectively). *C. cuculus* showed a critical length slightly lower than the L_{50}, whereas these values were quite similar for *T. lastoviza*. Both *S. cabrilla* and *T. draco* showed critical lengths higher than the L_{50} (Table 4.2 and 4.3). The SSB represented 24, 40, 56 and 58% of the mean annual biomass for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively (Table 4.3). The *F* by size class remained similar irrespective of the F_t that had been used (Figure 4.9). In this sense, the species showing the highest variability was *C. cuculus*, although these variations were low and appeared only for the largest and less

abundant size classes. Among the species studied, the largest and smallest populations corresponded to *T.draco* and *T. lastoviza*, respectively (Table 4.3).

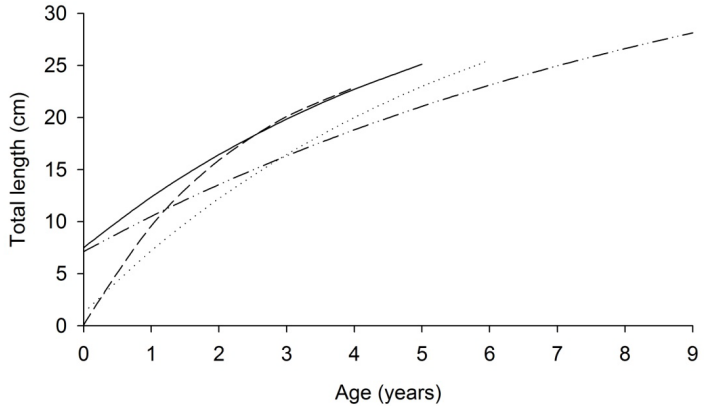


Figure 4.6. Fitting of von Bertalanffy growth function to age-length data of the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

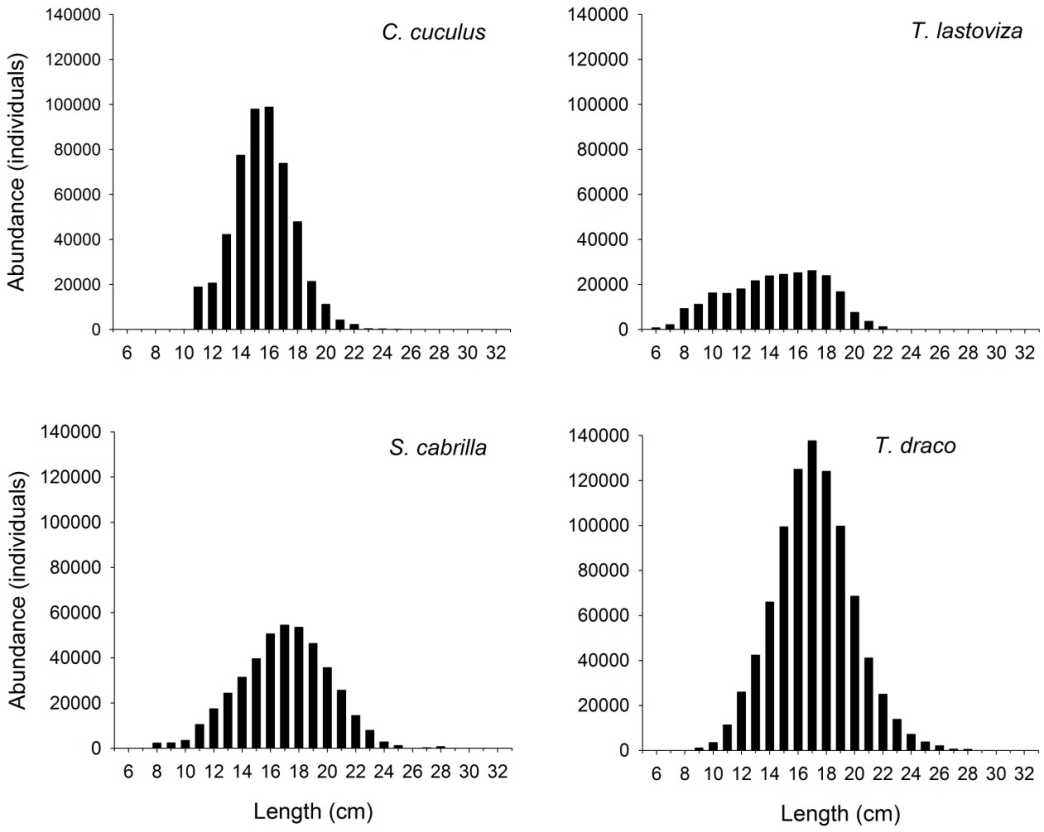


Figure 4.7. Length frequency distribution of catches (pseudo-cohorts built with data collected on board between 2008 and 2010) for the studied species.

The Y/R analyses showed that, for all the studied species, the current *Y/R* was below the Y/R_{max} and $Y/R_{F0,1}$ (Table 4.3; Figure 4.10). Y/R_{max} could be achieved by reducing the current fishing mortalities of *C. cuculus, T. lastoviza, S. cabrilla* and *T. draco* by 65.2, 69.2, 71.8 and 72.5%, respectively. Slightly lower reductions of 66.8 and 69.4 for *C. cuculus* and *T. lastoviza*, respectively, and 73.1% for both *S. cabrilla* and *T. draco* are needed to achieve the reference point $Y/R_{F0,1}$ (Table 4.3). Compared to the virgin stock biomass, the mean biomass was low for all species, representing 10, 2, 11 and 3% for *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*, respectively.

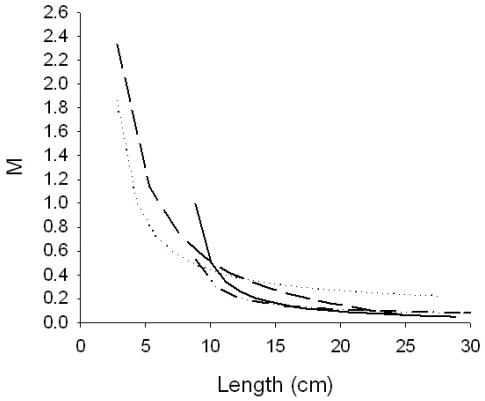


Figure 4.8. Natural mortality (*M*) vector by length class for the studied species. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines.

Table 4.3. Summary of the results of the Virtual Population (VPA) and Yield per Recruit (Y/R) analyses for the studied species. The value of terminal fishing mortality (F_t) used was 0.2 in all cases. Biomass is in kg; lengths in cm; ages in years; inputs, outputs and biomass turnover in %; *F* is the fishing mortality; Yield per recruit (*Y/R*) is in g; Y/R_{max} is the maximum sustainable yield; $Y/R_{F0.1}$ is the yield per recruit at a fishing mortality rate corresponding to 10% of the slope of the yield-per-recruit curve at the origin; Φ is the effort factor; Φ_{max} and $\Phi_{F0.1}$ are the Φ corresponding to the Y/R_{max} and $Y/R_{F0.1}$, respectively.

		C. cuculus	*T. lastoviza*	*S. cabrilla*	*T. draco*
Catches					
Number		518107	248813	426724	899766
Biomass		19486	10405	26148	32787
Mean length		16.0	14.9	17.4	17.6
Mean age		1.92	1.90	3.3	3.56
		VPA			
Mean annual number		708624	447500	1465689	3660410
Mean annual biomass		18444	9322	44600	67265
Recruits		672364	494891	995359	1837534
Spawning Stock Biomass		4400	3684	24997	38736
Mean length		14.1	11.3	13.1	13.6
Critical length		14.0	15.0	16.0	16.0
Mean age		1.43	1.30	2.28	2.88
Critical age		1.38	1.83	2.89	3.03
Total biomass balance (D)		22769	13585	40664	44704
Inputs	Recruitment	31.4	8.3	14.3	17.7
	Growth	68.6	91.7	85.7	82.3
Outputs	Natural death	14.4	23.4	35.7	26.7
	Fishing mortality	85.6	76.6	64.3	73.3
Biomass turnover		123.5	145.7	91.2	66.5
Global F		0.72	0.56	0.29	0.25
		Y/R			
Current *Y/R*		29.2	21.2	26.4	17.9
Y/R_{max}		34.8	30.8	28.2	27.5
Φ_{max}		0.41	0.23	0.55	0.22
$Y/R_{F0.1}$		33.2	30.6	26.9	26.9
$\Phi_{F0.1}$		0.27	0.15	0.34	0.16
Virgin stock biomass		192024	590436	423841	2538665

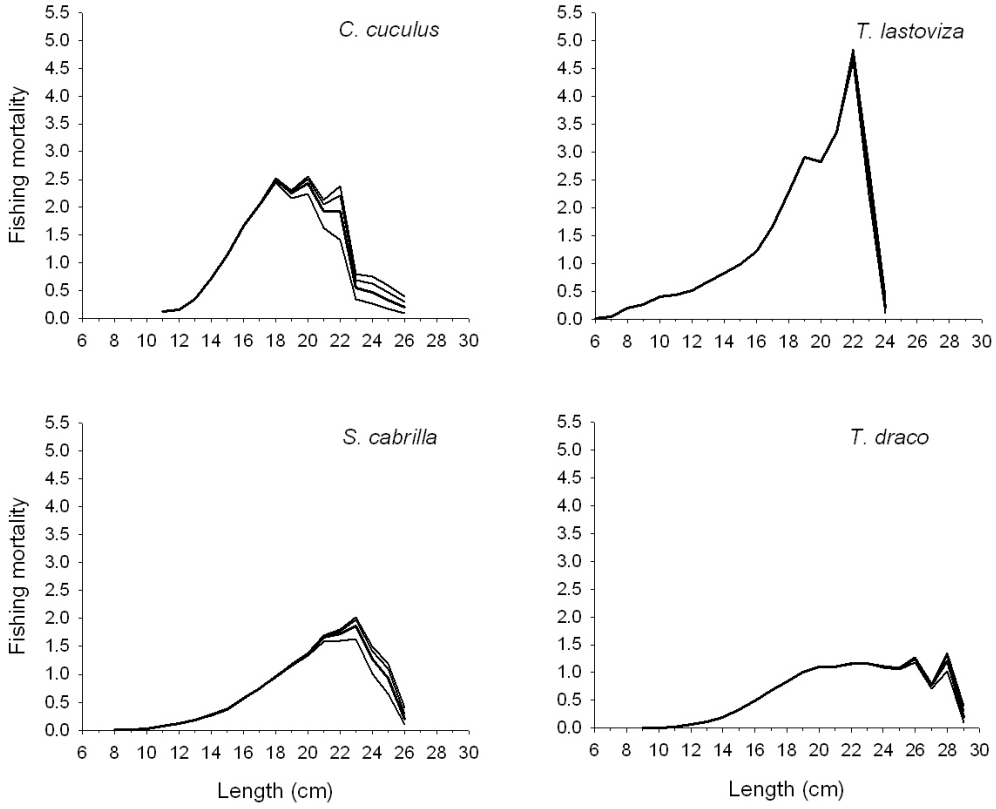


Figure 4.9. Fishing mortality by length class for the studied species. Terminal fishing mortality (*Ft*) values of 0.1, 0.2, 0.3 and 0.4 were tested. The bold line represents the final value of *Ft* (0.2) selected for further analyses.

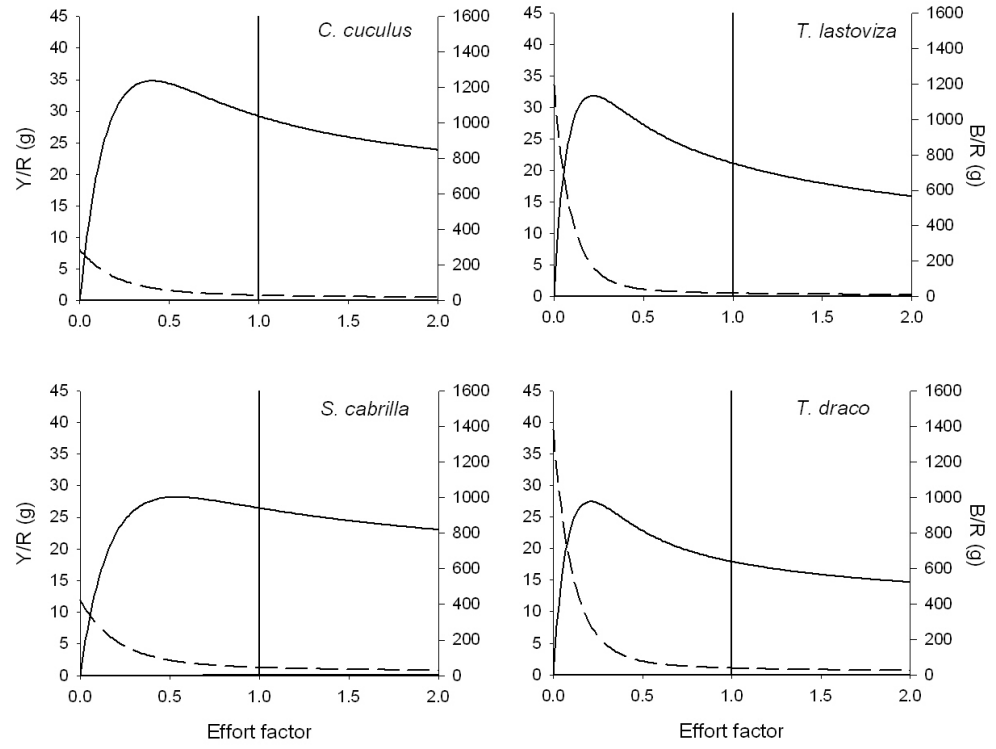


Figure 4.10. Results of the Yield per Recruit (Y/R) analysis. The continuous line represents the *Y/R* and the dashed line the Biomass per Recruit (*B/R*) for the studied species The current effort factor (1.0) is shown with a line.

4.3.4 Fishery independent indicators

The time series of the average stratified abundance and biomass of the studied species showed an oscillatory behaviour in all cases but without a significant trend for any of them (Table 4.4, Figure 4.11). The distribution range indicator did not show any significant trend for any of the studied species (Table 4.4, Figure 4.12). The percentage of occurrence in sampled grids ranged from 10% in 2001 to 26% in 2011 for *C. cuculus*, from 10% in 2002 to 23% in 2011 for *T. lastoviza*, from 24% in 2004 to 31% in 2007 for *S. cabrilla* and from 32% in 2004 to 27% in 2005 for *T. draco*.

The CSF*b* showed an ascendant significant trend (R^2= 0.47; t_6= 2.66; p< 0.05) during the period 2004-2011, taking values higher than those of the reference state in 4 of the 8 years considered (Figure 4.13). Furthermore, regression analyses of the evolution of the proportion represented by the abundance of large individuals in relation to the reference period at species level showed an ascendant significant trend for all species except *T. lastoviza* (Table 4.4, Figure 4.14).

Table 4.4. Results of the linear regression analyses of the time series of stratified abundance and biomass, distribution range indicator ($\%C_{+i}$) and the proportion represented by the abundance of large individuals in relation to the reference period 2001-2003 ($\%0.5L_\infty$). The value of the t-test testing for the significance of the slope is shown. All significant slopes were positive (figure 4.14). Degrees of freedom are 9 for abundance, biomass and $\%C_{+i}$, and 6 for $\%0.5L_\infty$. *: p< 0.05 and **: p< 0.01.

Species	Parameter	t	R^2
C. cuculus	Abundance	1.36	0.08
	Biomass	1.68	0.15
	$\%C_{+i}$	1.98	0.23
	$\%0.5L_\infty$	3.31*	0.59
T. lastoviza	Abundance	0.89	0.02
	Biomass	1.15	0.03
	$\%C_{+i}$	2.18	0.27
	$\%0.5L_\infty$	0.68	0.08
S. cabrilla	Abundance	1.05	0.01
	Biomass	1.38	0.08
	$\%C_{+i}$	-0.12	0.11
	$\%0.5L_\infty$	3.7**	0.65
T. draco	Abundance	1.34	0.07
	Biomass	1.94	0.22
	$\%C_{+i}$	-1.14	0.03
	$\%0.5L_\infty$	2.94*	0.52

4.4 Discussion

In the period analyzed, 2001-2011, the MFC had similar or even larger landings than those of the main target species on the shallow shelf, *M. surmuletus* and *S. smaris*, and the deep shelf, *M. merluccius*. The four species taken into account are important components of the MFC, representing a large percentage of the landed biomass of this commercial category (54%). Although

there are two other species with similar importance, *S. notata* and *P. erythrinus*, the information on their length frequency distribution was too scarce to analyze their population dynamics and exploitation state.

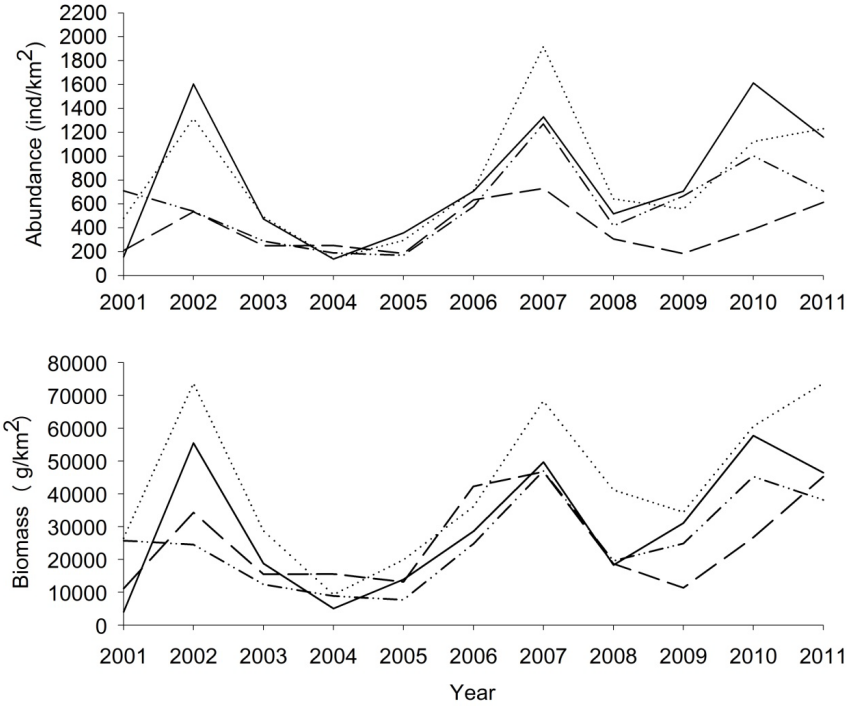


Figure 4.11. Temporal evolution of the average stratified abundance and biomass for the studied species obtained from MEDITS surveys data. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines. Linear regression analyses did not show any significant trend, neither for abundance nor for biomass, for any of the studied species.

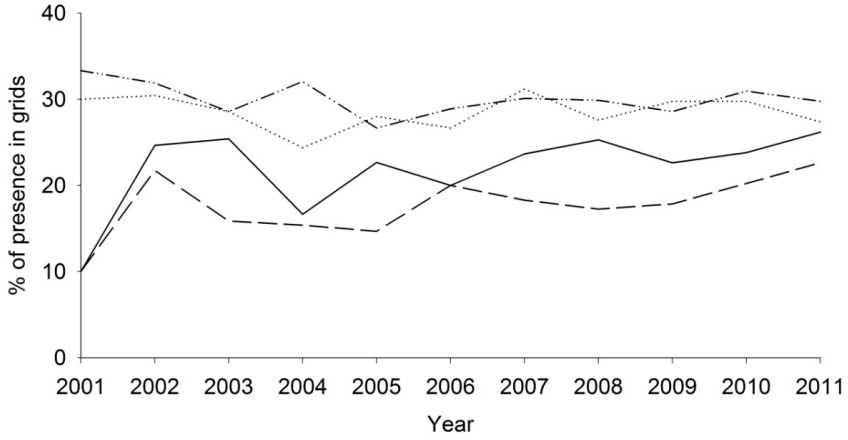


Figure 4.12. Temporal evolution of the distribution range (% of presence in grids) for the studied species obtained from MEDITS surveys data. *Chelidonichthys cuculus*: continuous lines; *Trigloporus lastoviza*: dashed lines; *Serranus cabrilla*: dotted lines; *Trachinus draco*: dash-dotted lines. Linear regression analyses did not show any significant trend, neither for abundance nor for biomass, for any of the studied species.

Similar biological traits have been found for the four demersal species considered in this study, *C. cuculus*, *T. lastoviza*, *S. cabrilla* and *T. draco*. They live on the continental shelf, with L_{50} (14-17 cm) and a relatively short life span (a maximum of 4 years detected for *T. lastoviza* and 9 years for *T. draco*), and are important components of the demersal communities from the continental shelf off the Balearic Islands, both in abundance and biomass (Massutí and Reñones, 2005; Ordines and Massutí, 2009). Despite the importance of these species as by-catch for the bottom trawl fishery in the Balearic Islands, little is known about their biology and, unlike target species, their exploitation levels have not been previously assessed. In fact, there are few studies addressing the most important traits of the biology of these species in both the Mediterranean and the Atlantic, especially in the case of *T. lastoviza* and *T.draco* (Annex 4.1). Moreover, the values of the parameters of growth and maturity gathered from the literature available may present differences even if we reduce the scope to the Mediterranean, e.g. the *k* and L_{50} of *S. cabrilla* vary from 0.1 to 0.4 years^{-1}, and 10 to 15.2 cm in standard length, respectively (Annex 4.1). In general, the values of the main biological parameters calculated in the present work are similar, or fall within the ranges of the values calculated in previous studies. This was not the case for the von Bertalanffy *k* parameter for *T. lastoviza*, available only from Tunisia where it is lower (0.13 years^{-1}) (Boudaya et al., 2010; Annex 4.1) than that reported in the present work (0.41 years^{-1}), and the larger values of L_{∞} for *S. cabrilla* and *T. draco* reported for the Balearic Islands.

Within the framework of the General Fisheries Commission for the Mediterranean (http://www.gfcm.org), the traditional single-species approach based on target species has predominated in the assessment of demersal fisheries, focusing mainly on *M. surmuletus* and *M. merluccius* (e.g. GFCM, 2012). The management of these fisheries, based on this approach, would also benefit by-catch species and habitats because by reducing the excessive fishing mortalities of target species to sustainable levels the pressure on the rest of the components of the ecosystem would also decrease (Mace, 2004). However, not all of the affected species are equally resilient. A clear example is that of the elasmobranches, which are a usual by-catch species of demersal fisheries in the Mediterranean (Guijarro et al., 2012) and are considered highly vulnerable due to their k-selected life-history strategy, characterized by slow growth, late attainment of sexual maturity, long life spans and low fecundity (Stevens et al., 2000). The different resilience of the species involved in a fishery could lead the most vulnerable components of the ecosystem to collapse if fishery management only takes into account the assessment of target species and they are among the most resistant.

Our results show that the main by-catch species of the trawl fleet operating on the continental shelf off the Balearic Islands must be considered as overexploited. The reduction in fishing effort required to reach the $Y/R_{F0,1}$, considered as a reference point for management targets for sustainable fisheries (GFCM, 2014), is lower (67-73%, depending on the species) to that required in the case of *M. merluccius* ($Y/R_{F0,1}$= 87%), but higher than that required for *M. surmuletus* ($Y/R_{F0,1}$= 53%) for the period 2000-2010, the two target demersal species periodically assessed in the area (GFCM, 2012). Hence, reducing the fishing effort on the shallow shelf in order to achieve the

$Y/R_{F0,1}$ of *M. surmuletus*, would not suffice to achieve the same target for the by-catch species studied here, especially for *T. lastoviza*, *S. cabrilla* and *T. draco*, whose largest parts of their populations live on the shallow shelf, as is also the case for *M. surmuletus* (Massutí and Reñones, 2005). It should be noted here that the mentioned reference points made our results comparable to those of the periodically assessed species. However, as is the case of *M. merluccius*, whose population of largest individuals is considered to be not fully available to the trawl fishery (Caddy, 1993), some of the species assessed in the present work may also share this characteristic. This could be the case of *S. cabrilla*, a species present in most of the habitats of the continental shelf, including rocky bottoms (Fischer et al., 1987) not available to trawling. Hence, the population of *S. cabrilla* could be in a better state, or be more resilient to the trawling fishing pressure than suggested by the present assessment, which is restricted to the bottom-trawl fishery.

The fishery-independent indicators allowed completion of the fishery-dependent single species assessment. The data available for the by-catch species studied forced us to use VPAs based on pseudocohorts, yielding results that do not include any information of the trend of the state of the populations. This was supplied by the fishery-independent indicators. The average stratified abundance and biomass and the distribution range showed that the studied species are stable, while the Conservation Status of Fish indicator (CSF*b*) showed an overall positive trend, indicating a certain recovery. These results are in agreement with those obtained from the initial evaluation of the implementation of the MSFD in the study area (IEO, 2012), where most of the biodiversity indicators applied to fish species showed a Good Environmental State in the Balearic Islands. In the specific case of the CSF*b*, the reported trend of this indicator in the MSFD was almost identical to that reported here. Although the analyses for the MSDF included a higher number of fish species, according to Massutí and Reñones (2005), most of these species are mainly distributed on the continental shelf (41%, i.e. *C. cuculus*, *M. surmuletus*, *Pagellus erythrinus*, *Scorpaena scrofa*, *S. cabrilla*, *T. draco* and *Zeus faber*) or on both the continental shelf and upper slope (41%, i.e. *Helicolenus dactylopterus*, *Lepidorhombus boscii*, *M. merluccius*, *Peristedion cataphractum*, *Raja clavata*, *Trygla lyra* and *Scyliorhinus canicula*), whereas only 18% were species typically distributed on the slope (i.e. *Galeus melastomus*, *Micromesistius poutassou* and *Phycis blennoides*). During the last decade, the trawl fleet operating in the Balearic Islands has displaced its fishing effort from the shelf to the slope, targeting the economically most valuable demersal resource in the area, the red shrimp *Aristeus antennatus* (Hidalgo et al., 2009). This seems to be already positively affecting fish populations of the shelf. This is the case for the elasmobranch community living on the shelf bottoms of the study area, showing a slight recovery during the last decade, which has not been observed for the same community on the slope (Guijarro et al., 2012).

Although the time series of the average stratified abundance and biomass did not show any clear trend, all the species analyzed showed a similar pattern of oscillations. Similarly, inter-annual fluctuations have also been detected for other species in the same study area, both on the shelf and the slope (Quetglas et al., 1998; Carbonell et al., 1999; Quetglas et al., 2013). While these fluctuations were attributed to meso- and large-scale climatic indices in the case

of species with broader age structure and longer life span, global scale indices seemed to influence the populations of species with a narrow age structure and short life span, especially species inhabiting the continental shelf (Quetglas et al., 2013). Although the short time series available for the present study prevents further analysis, the similarity in the pattern of oscillations among the species analyzed suggests that it may also be the result of a similar response to climatic forces.

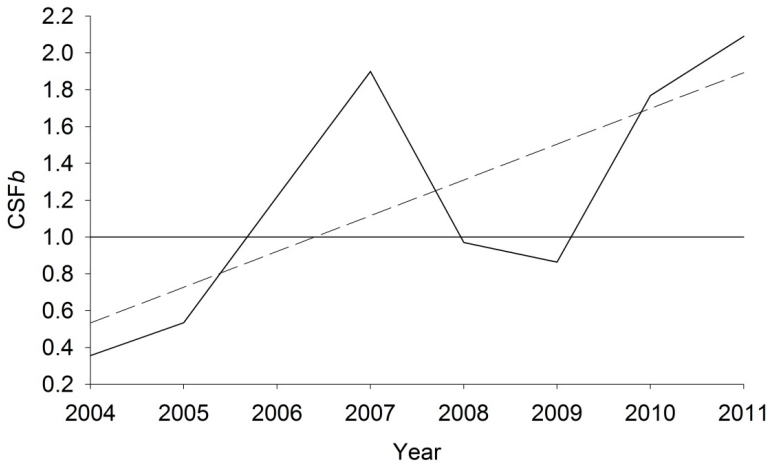


Figure 4.13. Temporal evolution of the Conservation Status of Fish *b* (CSF*b*) obtained from MEDITS surveys data. The horizontal line indicates the reference state. The discontinuous line represents the linear regression of CSF*b,* which shows an ascendant significant trend (R^2= 0.47; p< 0.05).

Our results may allow us to be more optimistic about the future of demersal species living on the continental shelf of the Balearic Islands, despite the fact that this may be at the expense of species living on the slope. However, they also underline the necessity of incorporating monitoring and assessment of by-catch species in fisheries management, given that their populations can show more pronounced overexploitation than target ones (in our case *M. surmuletus*). In the progressive change from single-species management to an ecosystem approach to fisheries (Browman and Stergiou, 2004) undertaken by the European Common Fisheries Policy for the Mediterranean in order 'to protect and conserve living aquatic resources and ecosystems' (Council Regulation EC 1967/2006), the "traditional" single-species assessment techniques will still be needed and fit perfectly, as long as their scope expands beyond the main target species.

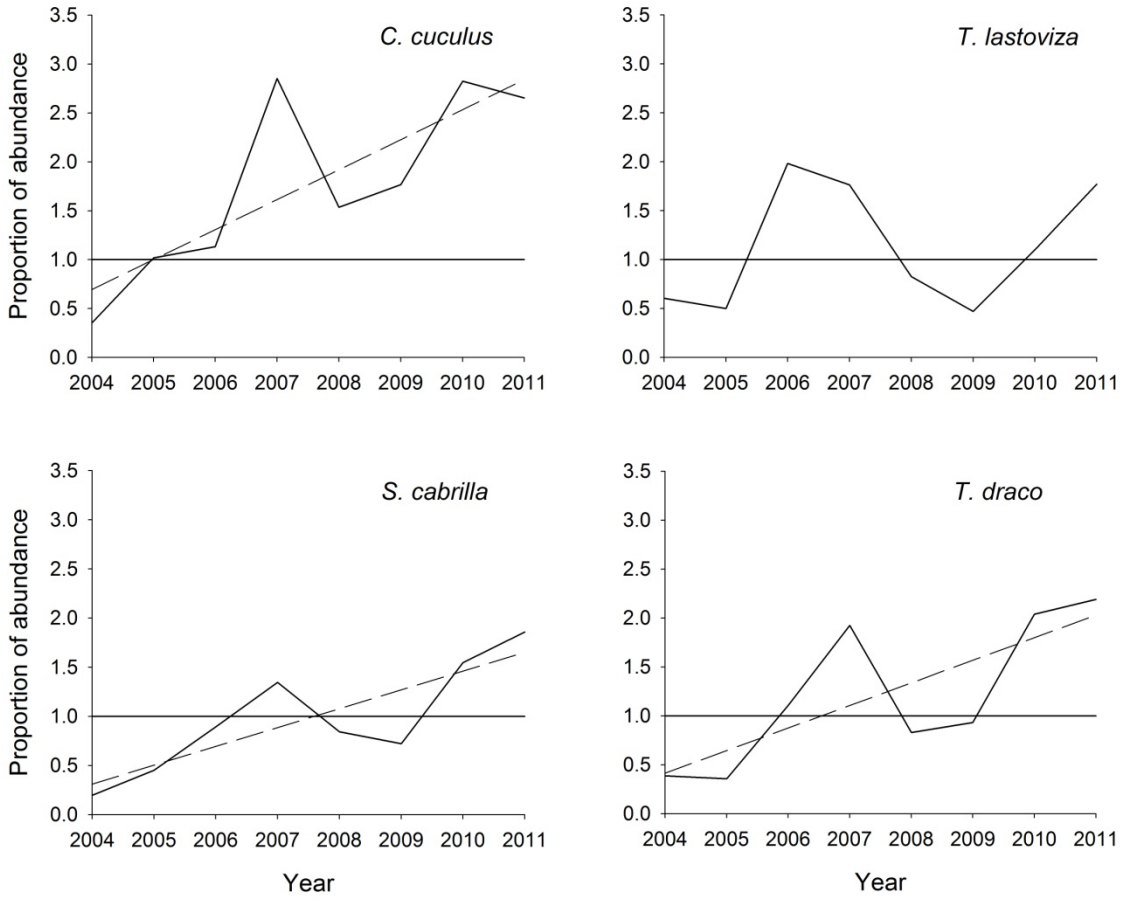


Figure 4.14. Temporal evolution of the proportion of the abundance of large individuals (≥ 0.5L_∞), in relation to the reference period for the studied species obtained from MEDITS surveys data. The horizontal line indicates the reference state. The discontinuous line represents the linear regression of the values, which shows an ascendant significant trend for *Chelidonichthys cuculus* , *Serranus cabrilla* and *Trachinus draco* (Table 4.4). No trend was observed for *Trigloporus lastoviza*.

Annex 4.1. Summary of the main biological parameters for each species. MED: Mediterranean, AT: Atlantic; TL range: total length range of the individuals studied; Age range: age range of the individuals studied; M: males, F: females, and T: both sexes.

Species	Study Area	TL range (cm)	Age range (years)	L_∞			k			L_{50}			Reference
				T	F	M	T	F	M	T	F	M	
C. cuculus	Aegean Sea (MED)		1-7		28	20		0.22	0.51				Papaconstantinou, 1983
	Mediterranean									19			Bauchot, 1987
	Gulf of Lion (MED)	10.-30	1-5	35			0.28						Campillo, 1992
	Adriatic Sea (MED)	10-36	1-5		29	29		0.40	0.41				Marsan et al., 1998
	Tyrrhenian Sea (MED)	7-27	1-3		24	23		0.74	0.59		18		Colloca et al., 2003b
	Adriatic Sea (MED)	10-26									17	15	Vallisneri et al., 2012
	Douarnenez Bay (AT)	14-45	1-21		42	37		0.46	0.52		28	27	Baron, 1985a; 1985b
	English Channel (AT)	9-43	1-4	36	41	36	0.24	0.24	0.23	25			Dorel, 1986; ICES, 2006
	Irish Sea (AT)	10-43	1-7	42	41	41	0.21	0.24	0.21	28	28	26	Marriott et al., 2010
T. lastoviza	Gulf of Lion (MED)											$19<L_{50}<21$	Kartas, 1971
	Greek waters (MED)											14	Papaconstantinou, 1986
	Egypt (MED)											15	Abdallah and Faltas, 1998
	Gulf of Gabès (MED)									14		15	Boudaya, 2000
	Gulf of Tunis (MED)	11-26								16	16	16	Ben Jrad et al., 2010
	Gulf of Gabès (MED)				33	30		0.13	0.13				Boudaya et al., 2010
	Douarnenez Bay (AT)											29	Baron, 1985
S. cabrilla	Tunis (MED)									10 (SL)			Bouain, 1981
	Mediterranean									15 (SL)			Bauchot, 1987
	Aegean Sea (MED)			26			0.30						Papaconstantinou et al., 1994
	Greek waters (MED)		1-8	24			0.30						Politou and Papaconstantinou, 1995
	Cretan Shelf (MED)	6-20	1-5	22			0.39						Tserpes and Tsimenides, 2001
	Edremit Bay (MED)	9-22	1-4	34			0.11			15 (FL)			Torku-Koc et al., 2004
	Aegean Sea (MED)	7-23	1-6	24			0.30			13			İlhan et al., 2010
	Canary Islands (AT)									15 (SL)			García-Díaz et al., 1997
T. draco	Aegean Sea (MED)	15-37									16	15	Kınacıgil et al., 2008
	Black Sea (MED)	9-26	1-6	29	33	29	0.28	0.18	0.17				Ak and Genç, 2013
	Kattegat (AT)	9-40	1-14		38	35		0.15	0.16				Bagge, 2004

CHAPTER 5

Diamond *vs.* square mesh codend in a multi-species bottom trawl fishery

Adapted from: **Ordines F.**, Massutí E., Guijarro B., Mas R (2006). Diamond vs. squared mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. Aquatic Living Resources 19: 329-338. doi: 10.1051/alr:2007003

Abstract

Selectivity studies usually describe the effects on target species, whereas information on by-catch and discards is scarce. Nevertheless, large quantities of undersized individuals and invertebrates are discarded in the Mediterranean multi-species bottom trawl fishery. The present work analyzes the effect of a change of the mesh geometry in the codend of bottom trawl gears on catch composition, yield, size selectivity and discards. The mean selection length (SL_{50}) was clearly larger for most species using the 40 mm square mesh than using the 40 mm diamond mesh in force at the time that the present work was done. This allows many more individuals under their minimum landing size (MLS) to scape. On the shallow shelf, the yields of *Spicara smaris* were significantly lower by using the square mesh, changing the composition of the retained catch. Escapement ratio and economic loss were significantly higher with square mesh, although economic loss was almost negligible for both meshes on the deep shelf. The use of square mesh significantly reduced the discards of algae on the shallow shelf and fish on the deep shelf. The results confirmed that square mesh codend reduces the fishing pressure on small specimens as well as the impact of trawling on the ecosystem. These benefits would not lead to a reduction of the yields of any of the main target species except for *S. smaris*. However, despite the improvement in selectivity achieved by using the square mesh, the sizes at first capture still remain smaller than the size at first maturity for most of the species, and even smaller than the MLS in some cases. Further selectivity improvements should be implemented in order to assure the individuals of as much species as possible the opportunity to spawn before getting caught.

Keywords: bottom trawl; continental shelf; multi-species fishery; codend selectivity; diamond and square mesh; discards.

Cóp de malla ròmbica *vs.* cóp de malla quadrada a una pesquera de ròssec multiespecífica

Resum

Normalment els estudis de selectivitat descriuen els efectes sobre les espècies objectiu, mentre que la informació sobre les espècies 'by-catch' i el rebuig és escassa. No obstant això, a la pesquera de ròssec multiespecífica del Mediterrani es rebutgen grans quantitats d'individus per davall de la talla de primera captura i d'invertebrats. Aquest treball analitza l'efecte del canvi de la geometria de la malla al cop dels arts de ròssec sobre la composició, rendiment, talla de selectivitat i rebuigs. La talla de primera captura (SL_{50}) per a la majoria d'espècies fou clarament major emprant la malla quadrada de 40 mm que la ròmbica de 40 mm, usada legalment quan es va realitzar aquest treball. Això permet l'escapament de molts més individus per davall de la seva talla mínima legal (TML). A la plataforma costanera, els rendiments de *Spicara smaris* fou significativament més baix usant malla quadrada, provocant un canvi en la composició de la captura retinguda. La ràtio d'escapament i la pèrdua econòmica foren significativament més elevats usant malla quadrada, tot i que la pèrdua econòmica fou gairebé negligible amb ambdues malles a la plataforma continental profunda. La utilització de la malla quadrada reduí significativament el rebuig d'alga a la plataforma costanera i de peix a la plataforma profunda. Els resultats han confirmat que el cop amb malla quadrada redueix la pressió pesquera sobre els individus petits així com l'impacte del ròssec sobre l'ecosistema. Aquests beneficis no suposarien una reducció dels rendiments de cap de les espècies objectiu exceptuant *S. smaris*. Així i tot, a pesar de la millora en les talles de primera captura aconseguida usant la malla quadrada, aquestes talles encara queden per davall de les talles de primera maduresa de la majoria d'espècies, i fins i tot, en alguns casos, per davall de la TML. Es necessitarien futures millores per tal de garantir als individus del màxim nombre d'espècies possible l'oportunitat de reproduir-se abans d'ser capturats.

Paraules clau: Ròssec; plataforma continental; pesquera multiespecífica; selectivitat del cop; malla ròmbica i quadrada; rebuig.

5.1 Introduction

The Mediterranean bottom trawl fisheries are multi-species and exert a high fishing pressure on the younger and immature individuals (Caddy, 1993). The poor selectivity of this fishery, with a minimum 40 mm diamond-shaped mesh in force at the time of the present work, means that a large number of individuals from the target species are caught under their minimum landing size, which increases the mortality of these species, preventing any economic profit, and also decreases their yield per recruit. It also has indirect effects on other by-catch and non-commercial species, which contribute to the large quantities of fish and invertebrates discarded at sea, especially on the continental shelf (Carbonell et al., 1998; Sánchez et al., 2004). For these reasons, the improvement of trawl selectivity has been recommended by the General Fisheries Commission for the Mediterranean (GFCM), since it is considered to be a tool for reducing the impact of trawling on the ecosystems and improving the exploitation pattern of target species (GFCM, 2001).

The codend mesh design has been established as an important factor determining the selectivity of a trawl (e.g. MacLennan, 1992). The diamond-shaped mesh in the codend stretches during the tow, hence reducing its selectivity when compared to the square mesh, which remains open (Robertson and Stewart, 1988). Several studies have been conducted to assess the selectivity of these two types of mesh in the codends, both in the Atlantic (e.g. Campos et al., 2003) and the eastern Mediterranean (e.g. Petrakis and Stergiou, 1997; Stergiou et al., 1997). In the western Mediterranean, the information on the performance of square-shaped mesh in the codend is limited to the trawl fishery on the shelf off the Ebro River delta and the Gulf of Lions (Bahamón et al., 2006, Mallol et al., 2001), and on the slope off the Balearic Islands (Guijarro and Massutí, 2006). These studies have pointed out that the introduction of square-shaped mesh in the codend could be a useful management measure for consideration in the Mediterranean. However, these results can not be extrapolated for the whole area because trawl selectivity also depends, among other factors like gear, vessel or environment (Wileman et al., 1996), on the biocenoses (MacLennan, 1992).

The continental shelf off Mallorca and Menorca (Balearic Islands) is narrow and mainly dominated by rocky, carbonate and gravel bottoms, in contrast to the terrigenous-dominated bottoms of the north-western Mediterranean (Canals and Ballesteros, 1997). This factor, along with others such as fishing exploitation, could be the reason for certain differences related to discards, demersal resources and exploited sensitive habitats and vulnerable species observed between trawl fisheries in the insular and peninsular shelf grounds: (i) discards represent up to 70% of the captured biomass off Mallorca (Carbonell et al., 1998) and 35% off the Catalan coast (Sánchez et al., 2004); (ii) of the two target red mullet species, *Mullus surmuletus* is more abundant than *M. barbatus* in insular assemblages although the opposite situation is found closer to the mainland (Massutí and Reñones, 2005); (iii) according to these authors, grounds off the Balearic Islands have large quantities of non commercial species (red algae and echinoderms represent 55-75% of the biomass in the exploited communities) and maërl beds are found in some areas; (iv) the Balearic Islands show higher diversity and abundance of

elasmobranchs compared to adjacent waters off the Iberian Peninsula (Massutí and Moranta, 2003). Almost 40 trawlers undertake their fishing activity off Mallorca, the largest island of the Balearic Archipelago, where they operate on the continental shelf and slope. Although landings from the slope are mainly composed of a few decapod crustacean species (Guijarro and Massutí, 2006), which have a higher economic value, the landings from the continental shelf are the most important in terms of biomass, since they are composed of a high number of fish species and some cephalopods.

The available works describing the effect of a change from diamond mesh to square mesh in the codend, are usually focused on target species. In the Mediterranean, only two works extend their analysis to the effects on catch composition, Stergiou et al. (1997) in the eastern Mediterranean, and Guijarro and Massutí (2006) for a slope bottom trawl fishery in the western Mediterranean. This information could be useful to develop a fisheries management in which the impact of fishing on the communities exploited is also taken into account, the so-called ecosystem approach. Our aim has been to contribute to the knowledge of selectivity by comparing under commercial conditions, a diamond mesh codend and a square mesh codend in the continental shelf bottom trawl fishery off the Balearic Islands (western Mediterranean). Hence, catch composition, yields, size selectivity of both target and by-catch species, and discards were compared between the two mesh types.

5.2 Material and methods

Sampling was conducted in traditional continental shelf fishing grounds off southern Mallorca (Balearic Islands, western Mediterranean; Figure 5.1) during September-October 2002 and May-June 2003, on board the commercial bottom trawler F/V “Moralti Nou” (length 22 m; 59 grt; nominal engine power 365 hp) that operates in the area. Two different conventional polyethylene and polyamide “mallorquí” and “quadrat”-type bottom trawl nets were used, linked by steel and polypropylene sweeps to metallic and oval-shaped otter-boards (Annex 5.1 and 5.2). The trawl fleet on shallower and deeper shelf bottoms in the study area traditionally uses these gears, respectively.

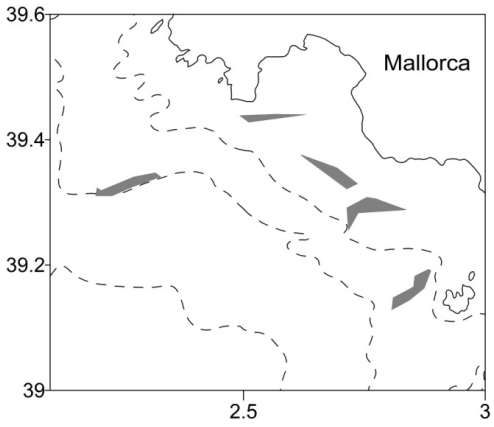


Figure 5.1. Map showing the sampled areas off the southern coast of Mallorca (Balearic Islands, western Mediterranean). Dashed lines correspond to isobaths of 100, 200 and 800 m.

Two codends of 40 mm nominal mesh size but with different mesh shape were assessed and each trawl type employed the covered codend method (Wileman et al., 1996). The codend cover was a diamond-shaped un-knotted polyethylene net with 20 mm stretched mesh attached directly to the funnel end of the net. In order to maintain a good flow of water and to avoid masking the codend meshes, the cover was 1.5 times wider and longer than the codends (Wileman et al., 1996).

A total of 24 trawl hauls were carried out during sunrise and followed routine commercial fishing procedures: 12 in 2002 at a depth of 50-78 m using the “mallorquí”-type net and 12 in 2003 at 147-189 m using the “quadrat”-type net. The duration of the hauls ranged between 1 and 2 hours and the towing speed between 2.6 and 3.6 knots. Each codend was used on the same gear and it was changed weekly, resulting in 6 hauls with each mesh and net type. After each haul, the crew and the scientific team sorted the catches in the codend according to taxonomic and commercial categories (landings and discards), and then the categories were counted and weighed separately. Total length (TL) and mantle length (ML) were measured for commercial species of fishes and cephalopods, respectively. Sub-sampling was done only to obtain the length distributions of *Spicara smaris* due to the great amount of individuals caught.

Trawl hauls were done on two different demersal resource associations that had been already described on the continental shelf off Mallorca (Massutí and Reñones, 2005): a shallower one located on the shallow shelf (SS) between 41 and 76 m of depth, and a deeper one on the deep shelf (DS) between 139 and 235 m of depth. Due to the differences in catch composition and assemblages exploited, the data analysis was done separately in each demersal resource association.

Redundancy analysis (RDA) was used to investigate differences in catch composition (kg/30 min) between mesh shapes of the most important commercial species retained in the codends. Monte Carlo free-distribution permutation based test was used to test the significance of the mesh shape effect. Bi-plot diagrams were produced but, since there was only one environmental variable in the model, the second axis needed to be interpreted as a first residual axis (ter Braak and Smilauer, 2002). Species appearing in less than 3 hauls were ommited from the analysis, as well as the species that were completely retained with both codend types (with the size of the individuals clearly larger than the mesh size), due to their variation in the yields should be completely unrelated to differences in selectivity of the codends. A RDA model followed with Monte Carlo test was also applied to test for overall differences in biomass (kg/30 min) of the main taxonomic groups discarded.

Commercial yields for the most important species and catch categories, total discarded catch and discards of main taxonomic groups (kg/30 min retained in the codend), as well as the composition of discarded fishes were calculated for both SS and DS, and mesh shape. The following indexes were also calculated: (i) escapement ratio or proportion of the escaped catch, as kg/30 min, in relation to the total catch; (ii) Economic loss or proportion of the value of the escaped commercial species, as €/30 min, in relation to the total

value; and (iii) economic efficiency or €/kg of the retained catch in relation to the total weight captured.

Gear saturation for both mesh shapes was analysed by attempting to fit a linear regression to the relationship between the escapement ratio and the retained catch by weight. It is hypothesised that the escapement ratio decreases with catch as the codend overfills, so a negative relationship would be expectable in the case of saturation.

A t-test was used to compare the commercial yields, discards, escapement ratio and economic indexes between mesh shapes. Prior to the use of the t-test, data were checked for the assumptions of normality and homogeneity of variance. When these assumptions were not met, data was log or square-root transformed (Underwood, 1981). Proportional data (x) were previously transformed to fit them to a normal distribution, according to the following expression: $\mathrm{X} = \arcsin\sqrt{\mathrm{x}/100}$.

When the number of individuals in the cover was enough, size selectivity parameters were estimated, by mesh shape, for the most important species on the SS and DS. The retention probability of individuals that entered in the codend (SL) for each length class (L) was modelled for each single haul, using the logistic selection curve, which assumes that the data are binomially distributed, $\mathrm{SL} = \mathrm{e}^{(\mathrm{S_1}+\mathrm{S_2}*\mathrm{L})}/(1+\mathrm{e}^{(\mathrm{S_1}+\mathrm{S_2}*\mathrm{L})})$; where S_1 and S_2 were the parameters to estimate. This logistic selection curve is one of the most recommended methods (e.g. Wileman et al., 1996). Mean selection length (SL_{50}, length at which the probability of being retained in the codend is 50%) and selection range ($\mathrm{SR}=\mathrm{SL_{75}}-\mathrm{SL_{25}}$) were calculated from the expressions $\mathrm{SL_{50}}=-(\mathrm{S_1}/\mathrm{S_2})$ and $\mathrm{SR} = (2*\ln(3))/\mathrm{S_2}$. Fitting of the selection curves for individual hauls was carried out by maximizing the log-likelihood function, using SOLVER in MS-EXCEL (Tokai, 1997). Goodness of fit was checked through a model deviance test and residual plots (Wileman *et al.*, 1996). Mean selectivity curves and variance matrix of S_1 and S_2 estimates were calculated taking into account the inter-haul variability by using the ECWeb (ConStat) software and following the methodology proposed by Fryer (1991). ECWeb software was also used to compare selection curves when individual haul fits were available for both kinds of mesh. The comparison was done by testing whether the differences between the two meshes for each parameter estimate (S_1 and S_2) were significantly different from zero (Fryer, 1991). Alternatively, when the number of individuals retained and escaped in single hauls was insufficient, logistic parameters were estimated from pooled data.

5.2 Results

The 24 trawl hauls carried out yielded 4205 kg of total landings, which represented an economic value of 9908 €. The commercial species caught were comprised of 57 fishes, 8 cephalopods and 2 decapod crustaceans, which represented 92.4, 7.5 and 0.1% of the landings, respectively, in terms of biomass. The most important species were *Spicara smaris* (53% of landed

biomass), *Mullus surmuletus* (5%), *Loligo vulgaris* (4.5%), *Trachurus mediterraneus* (4%), *Pagellus acarne* (4%), *Aspitrigla cuculus* (3.5%) and *Zeus faber* (3%). From an economical point of view, the most important commercial species or catch categories were *S. smaris* (25.5%), *L. vulgaris* (20%), *Z. faber* (16.5%), *M. surmuletus* (10%) and the mixed fish category (8%).

The most important commercial categories in both biomass and commercial value are summarized on Table 5.1. RDA on the catch biomass of the species present in those categories showed significant differences in the composition between mesh shapes on the SS (Figure 5.2).

Table 5.1. Catch biomass (kg/30 min±S.E) of the most important commercial categories captured (comprising >98% of the total commercial value for SS and DS, and 99% and 94% of the total biomass of commercial species for SS and DS respectively) and t-test results comparing between mesh shape yields (ns: non significant; *: p< 0.05; **: p< 0.01). Mean price of the species (€/kg) and percentage of the total commercial value (%V) are also presented.

Taxon	Diamond	Square	%V	Price	t-test
	Mean ± S.E.	Mean ± S.E.			
Shallow shelf					
Teleosts					
Lophius spp.[1]	0.74 ± 0.24	0.26 ± 0.19	1.8	7.21	ns
Mixed fish[2]	10.15 ± 1.95	12.50 ± 1.98	11.7	2.08	ns
Mullus surmuletus	2.43 ± 0.74	4.21 ± 2.20	8.4	4.21	ns
Scorpaena scrofa	0.14 ± 0.07	0.45 ± 0.19	1.5	12.17	ns
Spicara smaris	106.03 ± 21.03	20.68 ± 4.44	37.1	1.34	**
Trachurus mediterraneus	4.69 ± 1.68	4.21 ± 0.81	1.2	0.41	ns
Zeus faber	0.59 ± 0.20	0.40 ± 0.20	3.2	12.24	ns
Elasmobranchs					
Raja spp.[3]	0.17 ± 0.13	0.36 ± 0.13	2.2	1.33	ns
Scyliorhinus canicula	0.83 ± 0.12	1.83 ± 0.45	0.8	0.76	ns
Cephalopods					
Loligo vulgaris	3.37 ± 0.55	6.64 ± 0.95	28.9	8.51	*
Octopuses[2]	2.17 ± 0.48	1.62 ± 0.30	1.8	1.67	ns
Deep shelf					
Teleosts					
Lepidorhombus boscii	0.31 ± 0.06	0.61 ± 0.04	2.7	4.84	**
Lophius spp.[1]	0.96 ± 0.13	0.72 ± 0.16	5.5	5.57	ns
Merluccius merluccius	0.62 ± 0.08	0.83 ± 0.18	5.5	5.7	ns
Mixed fish[5]	10.21 ± 1.68	8.74 ± 0.49	9.9	1.78	ns
Mullus surmuletus	2.13 ± 0.95	1.66 ± 0.44	12.2	5.19	ns
Scorpaena elongata	0.29 ± 0.29	0.17 ± 0.13	2.1	13.22	ns
Zeus faber	1.95 ± 0.51	4.33 ± 0.42	46.3	13.86	**
Elasmobranchs					
Raja spp.[6]	4.00 ± 0.44	4.40 ± 0.99	5.2	1.41	ns
Cephalopods					
Loligo vulgaris	0.35 ± 0.16	0.11 ± 0.04	3.8	12.62	ns
Octopuses[4]	1.95 ± 0.25	1.23 ± 0.18	4.7	0.84	*

[1.] *Lophius* spp included *Lophius budegassa* and *Lophius piscatorius* on both the SS and the DS. [2.] Mixed fish category on the SS included: *Chelidonichthys lastoviza*, *Serranus cabrilla*, *Trachinus draco*, *Pagellus erythrinus*, *Scorpaena notata*, *Pagellus acarne*, *Scorpaena porcus* and *Diplodus vulgaris*. [3.] *Raja* spp. category on the SS included *Raja miraletus* and *Raja radula*. [4.] Octopuses category on the SS and DS included *Octopus vulgaris* and *Eledone cirhosa*. [5.] Mixed fish category on the DS included: *Serranus cabrilla*, *Trachinus draco*, *Aspitrigla cuculus, Lepidotrigla cavillone*, *Citharus linguatula* and *Helicolenus dactylopterus*. [6.] *Raja* spp category on the DS included: *Leucoraja naevus*, *Raja brachyura* and *Raja clavata*.

The species that showed larger average abundances with diamond mesh were *S. smaris, Serranus cabrilla and Octopus vulgaris*, whereas *L. vulgaris*, *Chelidonichthys lastoviza, Scorpaena scrofa, Trachinus draco, S. canicula, Pagellus erythrinus, M. surmuletus* and *P. acarne* were more abundant with square mesh. No significant differences were found on the DS. The comparison of commercial yields between mesh shapes for the main species or catch categories showed few differences (Table 5.1). On the SS, catches of *S. smaris* were higher with diamond mesh, whereas catches of *L. vulgaris* were higher with square mesh. On the DS, catches of *L. boscii* and *Z. faber* were higher with square mesh, while for the octopus catch category the yields were higher with diamond mesh.

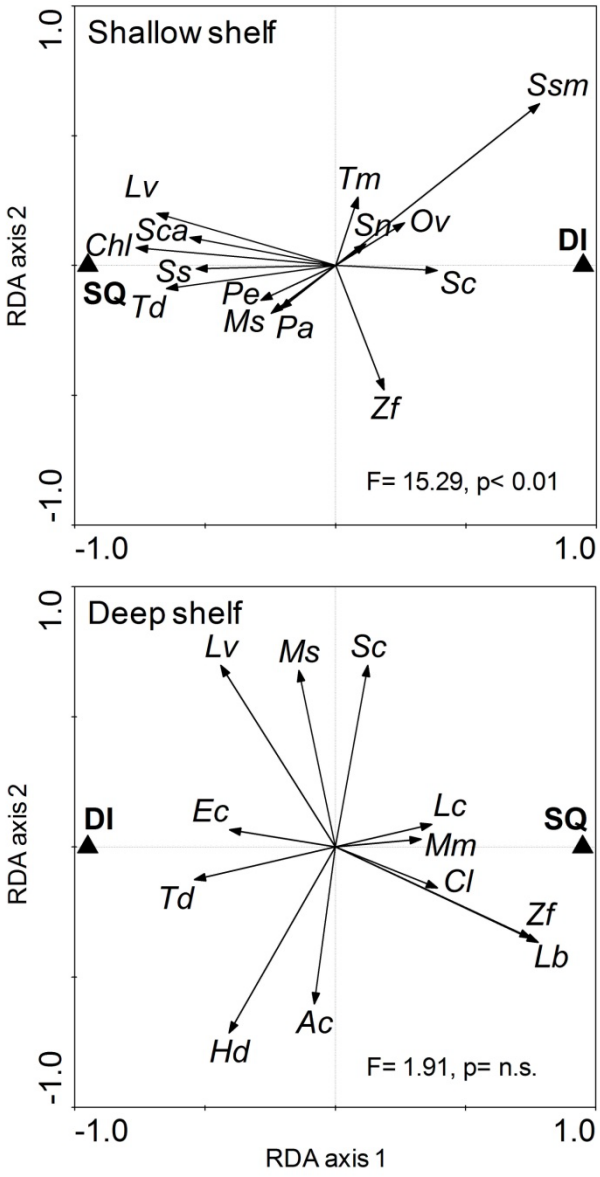


Figure 5.2. RDA results comparing catch biomass (kg/30 min) composition, by mesh shape of the most important commercial species (see Table 5.1). Triangles are the centroids (groups of samples) of each mesh shape, and their perpendicular projection on the line overlaying a species arrow indicates the average biomass of that species for each mesh shape. DI and SQ are diamond and square mesh respectively; ns: non significant; var. exp.: variance explained by the model. (*Ac: Aspitrigla cuculus; Chl: Chelidonichthys lastoviza; Cl: Citharus linguatula; Ec: Eledone cirrhosa; Hd: Helicolenus dactylopterus; Lb: Lepidorhombus boscii; Lc: Lepidotrigla cavillone; Lv: Loligo vulgaris; Mm: Merluccius merluccius; Ms: Mullus surmuletus; Pa: Pagellus acarne; Pe: Pagellus erythrinus; Ov: Octopus vulgaris; Sn: Scorpaena notata; Sca: Scyliorhinus canicula; Ss: Scorpaena scrofa; Sc: Serranus cabrilla; Ssm: Spicara smaris; Td: Trachinus draco; Tm: Trachurus mediterraneus; Zf: Zeus faber*).

On both the SS and DS, the escapement ratio and economic loss were significantly higher with square rather than diamond mesh (Figure 5.3). The economic efficiency with square mesh was higher than with diamond mesh on

the SS, whereas no differences were detected on the DS. No saturation was detected, because the relationships between the escapement ratio and the retained catch did not fit a linear regression: (i) on SS, p= 0.26 for diamond mesh and p= 0.08 for square mesh; (ii) on DS, p= 0.28 for diamond mesh and p= 0.30 for square mesh.

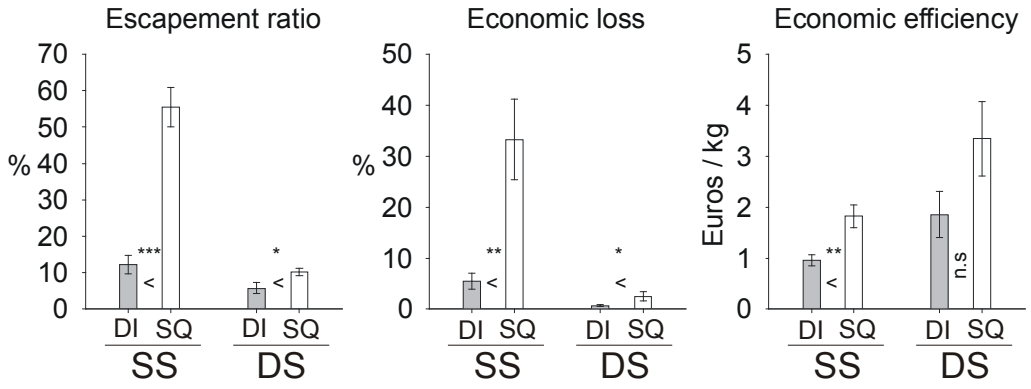


Figure 5.3. Mean (±S.E) escapement ratio, economic loss and economic efficiency for the shallow shelf (SS) and deep shelf (DS). T-test results comparing mesh shape are also shown (n.s.: non significant differences; *: p< 0.05; **: p< 0.01; ***: p< 0.001; DI: diamond mesh; SQ: square mesh).

The RDA model on the composition of the main taxonomic groups of discarded catches showed differences between mesh shape on the SS (variance explained= 46.8%, F= 8.8, p< 0.01) and the DS (variance explained= 16.6%, F= 2.0, p< 0.05). By taxonomic groups, discards of algae on the SS, mainly soft red algae (89%) and the green algae *Codium bursa* (8%), were higher with diamond mesh (t_{10}= -3.87; p< 0.01), while no differences between mesh shape were observed for any other group (Figure 5.4). This reduction was almost completely attributable to red algae (square mesh retained almost all the individuals of the green algae *Codium bursa* due to its size), and is remarkable since no differences were observed between meshes when summing codend and cover catches of red algae (t_{10}= -0.92, p= 0.48; with an average of 90.01 kg/30 min and 74.05 kg/30 min for diamond and square, respectively). On the DS, the only differences between mesh shape were observed in the discards of fishes (Figure 5.4), which were higher with diamond mesh (t_{10}= -2.82; p< 0.05). No differences between mesh shape were observed in the ratio between discarded commercial fishes and total discarded fishes: (i) on the SS t_{10}= 2.16, p= 0.14; (ii) on the DS t_{10}= 0.58, p= 0.64. On the SS, fish discards were composed in 79.7% of non commercial species (mainly *Boops boops* (63%) and *Serranus hepatus* (10%)) and 20.3% of commercial species (mainly *Scorpaena notata* (4.8%), *Raja miraletus* (4.3%) and *Trachurus mediterraneus* (3.4%)). On the DS, fish discards were composed in 90.5% of non commercial species (mainly *Capros aper* (40%), *Macrorhamphosus scolopax* (32%), *Synchiropus phaeton* (8%) and *Boops boops* (6%)) and 9.5% of commercial species (mainly *Scyliorhinus canicula* (2.9%), *Lepidotrigla cavillone* (1.4%) and *Aspitrigla cuculus* (1.1%)).

The main species of discarded commercial fishes were *Scorpaena notata*, *Raja miraletus* and *Trachurus mediterraneus* on the SS, and *Scyliorhinus canicula*, *Lepidotrigla cavillone* and *Aspitrigla cuculus* on the DS. The most important non commercial fishes were *Boops boops* (63%) and *Serranus hepatus* (10%) on the SS, and *Capros aper* (40%), *Macrorhamphosus scolopax* (32%), *Synchiropus phaeton* (8%) and *Boops boops* (6%) on the DS.

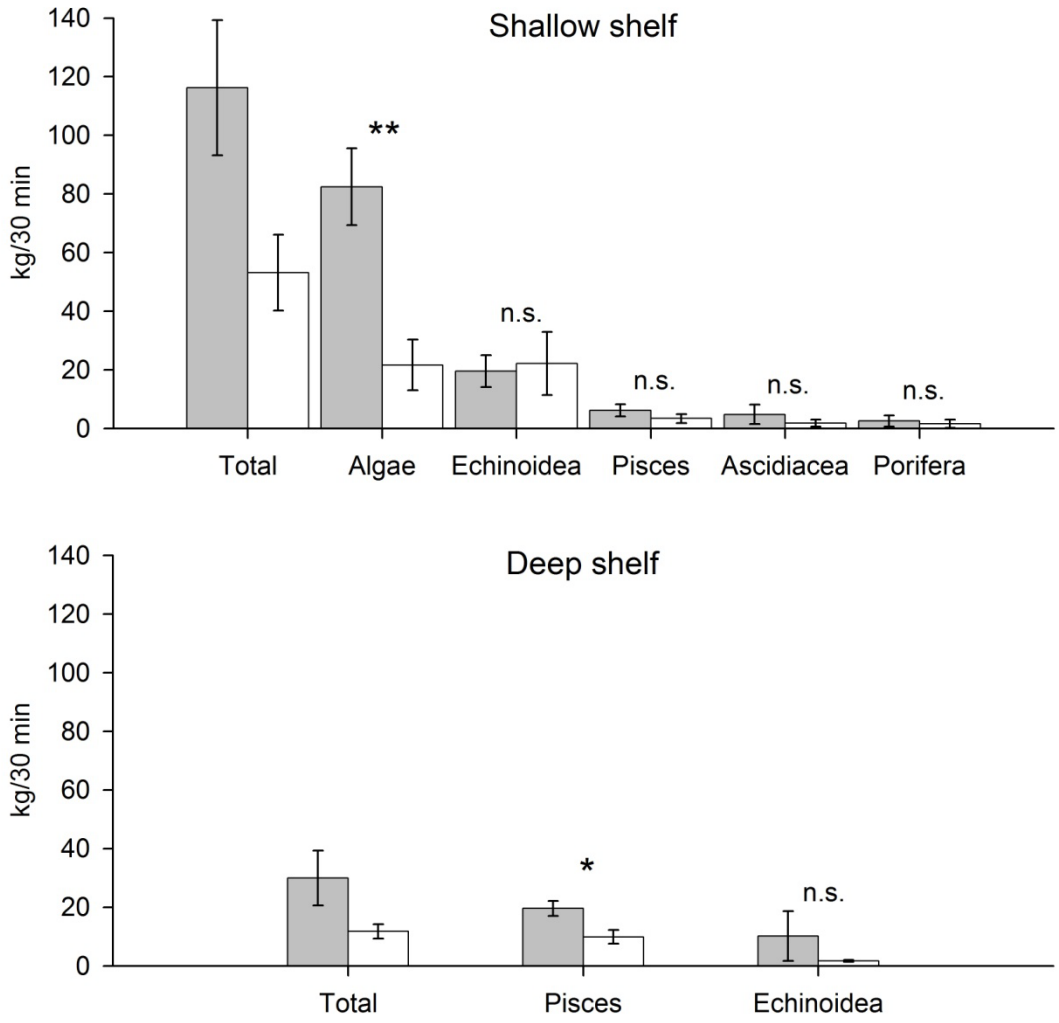


Figure 5.4. Mean biomass (kg/30 min±S.E) for total discards and for principal taxa (representing >99% of total weight discarded) for each mesh shape (grey: diamond mesh; white: square mesh). T-test results comparing mesh shape for each taxon are displayed (ns: non significant; *: p< 0.05 and **: p< 0.01).

Selectivity parameters and curves, calculated by mesh shape, taking into account between-haul variability or pooled data, are shown in Table 5.2 and Figure 5.5. In all species, there was a clear increase in the mean selection length from diamond to square mesh. Selection curves parameters obtained for *T. mediterraneus*, the one species in which individual haul fits where available for both meshes, were not significantly different depending on mesh shape (t_{15}= -0.95 and p= 0.36 for S_1; t_{15}= 1.76 and p= 0.10 for S_2).

Table 5.2. Selectivity parameters. S_1 and S_2: selection curve parameters estimates; SL_{50}: mean selection length; SR: SL_{75}-SL_{25}, selection range. When the selectivity parameters have been calculated by using the method of Fryer (1991), the variance matrix of S_1 and S_2 estimates (R_{11}, R_{12} and R_{22}) are presented, otherwise the selectivity parameters have been calculated from pooled data.

	Diamond							Square						
Species	S_1	S_2	SL_{50}	SR	R_{11}	R_{12}	R_{22}	S_1	S_2	SL_{50}	SR	R_{11}	R_{12}	R_{22}
Shallow shelf														
C. lastoviza	-2.858	0.604	4.7	3.6				-4.394	0.605	7.3	3.6			
M. surmuletus	-1.703	0.377	4.5	5.8				-12.580	1.030	12.2	2.1	6.899	-0.524	0.040
P. acarne								-4.889	0.520	9.4	4.2			
P. erythrinus								-11.575	1.110	10.4	2.0			
S. notata	-1.297	0.640	2.0	3.4				-17.870	1.837	9.7	1.2	19.100	-1.681	0.152
S. scrofa								-5.716	0.688	8.3	3.2			
S. cabrilla	-8.025	0.863	9.3	2.5				-11.420	0.808	14.1	2.7	5.024	-0.332	0.022
S. smaris	-3.906	0.433	9.0	5.1				-5.423	0.316	17.1	6.9			
T. mediterraneus	-14.230	1.038	13.7	2.1	0.980	-0.063	0.004	-11.130	0.733	15.2	3.0	4.275	-0.315	0.024
L. vulgaris	-3.752	1.099	3.4	2.0				-6.069	1.041	5.8	2.1	3.355	-0.392	0.047
O. vulgaris	-3.641	1.038	3.5	2.1				-6.029	1.001	6.0	2.2			
Deep shelf														
A. cuculus								-13.530	1.117	12.1	2.0	3.789	-0.254	0.017
C. linguatula								-17.209	1.498	11.5	1.5			
H. dactylopterus								-14.567	1.337	10.9	1.6			
L. cavillone	-11.803	1.694	7.0	1.3				-13.660	1.428	9.6	1.5	1.999	-0.213	0.023
M. merluccius	-7.129	0.673	10.6	3.3				-10.029	1.659	15.2	3.3			
S. canicula	-5.785	0.308	18.8	7.1				-8.978	0.313	28.7	7.0			
T. draco	-18.958	1.426	13.3	1.5				-14.985	0.826	18.1	2.7			
E. cirhosa	-0.912	0.556	1.6	3.9				-4.561	0.757	6.0	2.9			

5.4 Discussion

Studies on selectivity improvement are especially important in the Mediterranean because of the overall problem of the high proportion of immature specimens (or for some target species, specimens smaller than their minimum landing size) in trawl catches (Stergiou et al., 1997; Sánchez et al., 2004). In addition, in some areas such as the Balearic Islands, the shelf trawl fishery shows a great number of discards, mainly composed of algae and invertebrates (Carbonell et al., 1998). In the present study we have compared, under commercial conditions, the selectivity of a 40 mm diamond mesh codend and a 40 mm square mesh codend in the trawl fishery carried out on the continental shelf off the Balearic Islands. To deal with the multi-species characteristic of this fishery, the comparison was focused not only on selectivity parameters of the target species, most of them already studied in other Mediterranean areas (Petrakis and Stergiou, 1997; Bahamón et al., 2006), but also on catch composition, commercial yields and discards.

Differences in catch composition were observed between mesh shapes on the SS, mainly attributable to *Spicara smaris*, the most abundant species in terms of biomass. This species had a much higher scapement ratio with square mesh (up to 75%) than with diamond mesh (15% approximately). This difference can also be on the basis of the differences observed in the overall escapement ratio and economic loss, whose values with square mesh were clearly higher than with diamond mesh. No other significant losses in commercial yields of the main target species or categories were observed when using square mesh. By contrast, some species such as *Loligo vulgaris* on the SS or *Lepidorhombus boscii* and *Zeus faber* on the DS showed the highest yields with square mesh. These differences can be attributed to the between-haul variability of yields rather than mesh shape, because the escapement ratios for these fishes were similar with both meshes (almost null), while for the cephalopod it was almost null with the diamond mesh and around 10% with square mesh. On the DS, escapement ratio and economic loss also showed differences between both meshes, but economic losses were almost negligible in both cases (<1.5%), due to the relatively low value of small individuals.

The increase in escapement ratio with square mesh allowed a large quantity of biomass to escape, which would have otherwise been discarded. This is especially remarkable considering the large amounts of catches discarded on shelf bottoms (almost 120 kg/30 min on the SS and 30 kg/30 min on the DS). On the SS, discards were lower using square mesh, mainly due to a clear reduction of red algae (up to 60 kg/30 min), which also led to an increase of the economic efficiency. During the usual commercial fishing activity in the study area, most of the trawlers carry out a single haul on the SS, during the dawn, focussing successive ones on the DS or the slope crustacean fishery. Discarding is done during the navigation to the next haul location or during the next haul, and so, red algae are usually thrown on the DS or on the slope, where light intensity is not enough for the photosynthesis. Some of the predominant red algae species are free-living, which is the case for *Peyssonnelia* spp. (Ballesteros, 1994) or rodolith species, while others like *Osmundaria volubilis* and *Phyllophora crispa* live attached to the substratum (Ballesteros, 1992). Free-living species escaping through the mesh during the

haul could return to their habitat and keep on growing. The fact that these algae could remain on the SS fishing grounds is important because they are a great source of primary production below 40 m depth (Ballesteros, 1992), and also could play an important role on structuring the seafloor, even as detritic accumulations (Norkko et al., 2004). On the DS, a reduction of discarded fishes occurred (up to 10 kg/30 min; some of them commercial species), but no differences were observed for the echinoderms, which were the most abundant benthic group. In the Mediterranean, the effects of using square mesh in the codend on discards have been assessed only in the trawl shelf fishery of the Eastern Mediterranean (Stergiou et al., 1997), and on the slope of the western Mediterranean (Guijarro and Massutí, 2006). Both works reported a reduction of discards, although for the last case, the reduction was found in the middle, but not on the upper slope.

The estimation of size selectivity parameters using Fryer's methodology was only suitable for some species (*Mullus surmuletus*, *Scorpaena notata*, *Serranus cabrilla*, *Trachurus mediterraneus*, *Loligo vulgaris*, *Aspitrigla cuculus* and *Lepidotrigla cavillone*) and only for square mesh. As in other studies in the Mediterranean, the low captures and the poor selectivity of the 40 mm diamond mesh prevented to escape enough specimens to apply this method (Petrakis and Stergiou, 1997; Guijarro and Massutí, 2006). Most of species showed a clearly higher SL_{50} with square mesh. Moreover, for many species the retentions were close to 100% when using diamond mesh, indicating poor selectivity. As for the previous aspects analysed, the biggest differences in SL_{50} between meshes were obtained for *Spicara smaris*, with an increment from 9 to 17 cm. Although lower, increments in SL_{50} were also important for other target species such as *M. surmuletus* (5 to 12 cm) and *Merluccius merluccius* (10 to 15 cm). The estimated SL_{50} values for *S. smaris*, *M. surmuletus* and *M. merluccius* with the diamond mesh were clearly under the legal minimum landing size (MLS) in force (9 or 11 depending on the season, 15 and 20 cm, respectively) and also under their length at first maturity (12, 15 and 30 cm, respectively; Lozano-Cabo, 1953; Reñones et al., 1995; Oliver, 1993). By contrast, the SL_{50} values with the square mesh were larger than the MLS for *S. smaris* and *M. surmuletus*, although yet smaller for *M. merluccius*.

Improving the state of the resources by increasing SL_{50} depends upon a high survival rate of the escaped individuals. In this sense, the data available is scarce and even null in the case of Mediterranean trawl fisheries. In the north Atlantic, a study on gadoid fishes assessed the survival rates to be over 50% in the worst cases when testing different diamond mesh sizes (Sangster et al., 1996). To know the survival rates for Mediterranean fisheries and to determine the variations in these rates due to their multi-species nature is essential in order to assess the actual improvement that could be achieved with a change of mesh geometry.

The Balearic Islands have been reported to be one of the most diverse and abundant elasmobranches trawl assemblages in the western Mediterranean (Massutí and Moranta, 2003), these species being particularly vulnerable to fishing exploitation (Stevens et al., 2000). Different responses to the change of mesh geometry were observed in this group. While for the flatfish skates (*Raja* spp.) no improvement in gear selectivity was detected (total

retention with both meshes), the roundfish shark *Scyliorhinus canicula* showed a clear increase of SL_{50}, from 19 cm to 29 cm. This could be especially important on the DS, where juveniles of this species are abundant (Massutí and Moranta, 2003) and those smaller than 35 cm are usually discarded (Carbonell et al., 2003).

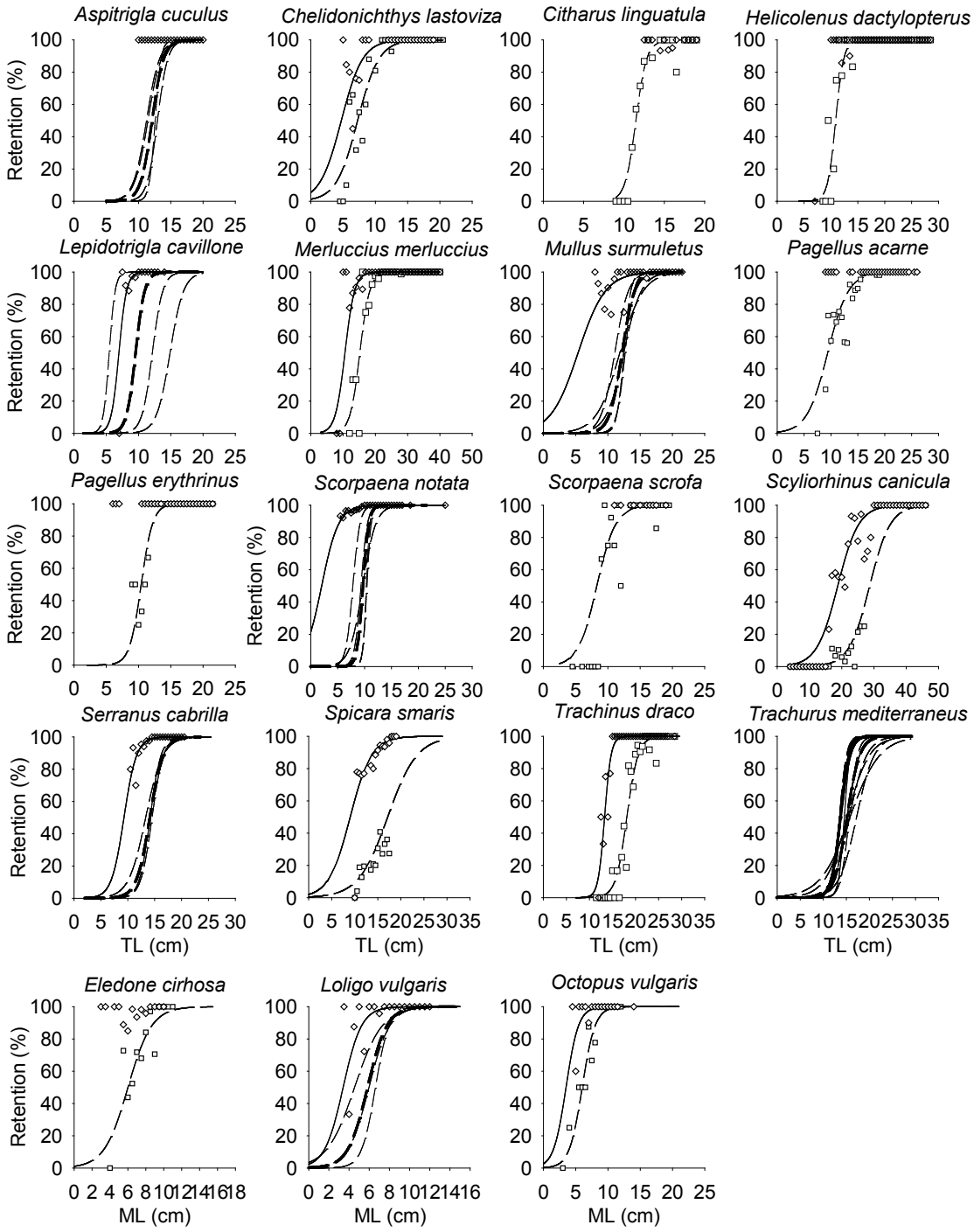


Figure 5.5. Selection curves of species in Table 5.2 (solid line: diamond mesh; dashed line: square mesh; observed values are diamonds and squares for respective mesh shape). When between-haul variation was taken in account, thin curves are the logistic curves by haul, whereas thick lines represent mean logistic curves. Only one curve is presented when estimation have been done using pooled data. TL: Total length; ML: mantle length.

One of the effects of overexploitation is a reduction of the size of the individuals, increasing the percentage of small specimens in the populations. For example, in the Gulf of Lions, individuals of *Merluccius merluccius* and *Mullus barbatus* below MLS represented up to 60 and 54% of the landed catch (Mallol et al., 2001). The change from diamond to square mesh has been reported as a good measure to reduce the percentage of undersized individuals for several species (Petrakis and Stergiou, 1997; Campos et al., 2003; Bahamón et al., 2006). This effect can also be observed in the present study (Table 5.3). However, mesh size was clearly not large enough to allow undersized individuals of species such as *Lophius* spp. to escape. This is a typical situation in multi-species fisheries, where species differing in body size and shape are present in the catch (e.g. Petrakis and Stergiou, 1997).

Table 5.3. Percentage of undersized individuals in relation to the total number of individuals retained and escaped (% <MLS), and percentage of undersized individuals escaped in relation to the total number of undersized individuals (% escaped) by mesh shape. MLS: minimum landing size of species appearing during the survey; n: total number of individuals retained and escaped.

		Diamond			Square		
Species	MLS	n	% <MLS	% escaped	n	% <MLS	% escaped
Diplodus vulgaris	15	85	3.5	0	200	67.0	0
Lepidorhombus boscii	15	67	11.9	0	120	5.8	14.3
Lophius budegassa	30	31	61.3	0	92	38.0	0
Lophius piscatorius	30	16	68.2	0	4	25.0	0
Merluccius merluccius	20	106	26.42	3.6	129	21.7	39.3
Mullus barbatus	11	76	0		112	0	
Mullus surmuletus	11	686	13.9	14.6	2031	9.3	74.7
Pagellus acarne	12	1024	1.7	0	2192	18.3	31.2
Pagellus erythrinus	12	136	4.4	0	146	12.3	55.5
Spicara smaris	11	97805	0.5	25.6	75828	0.8	96.9
Trachurus mediterraneus	12	2848	5.1	35.6	3350	7.1	90.3
Trachurus trachurus	12	51	19.6	89.8	6	50.0	0

Taking into account these results, the introduction of a 40 mm square mesh codend in the trawl fishery on the shelf off the Balearic Islands should reduce the fishing pressure on small specimens, leading to a subsequent improvement in the state of these resources. However, the improvement of the selectivity achieved by using square mesh is still far from guarantying the individuals of most of the species the opportunity to complete their vital cycle and reproduce before being caught. Besides the species for which the square mesh was not selective at all (e.g. *Raja* spp. and *Lophius* spp.), the size at first capture has only increased to a similar or a larger value than the reported size at first maturity for six out of the nineteen commercial species for which the square mesh showed a selectivity improvement (Table 5.4). Moreover, the size at first capture is even smaller than that of the smallest individuals reaching maturity of some of the species for which this information is available (Table 5.4). Despite this, when compared to the diamond mesh, the increase in SL_{50} with square mesh is enough to reduce the number of species caught under their MLS. Square mesh would also reduce discards, and hence the impact of fishing exploitation on the ecosystems. This would be especially important if we consider that sensitive maërl beds are found in some coastal fishing grounds off

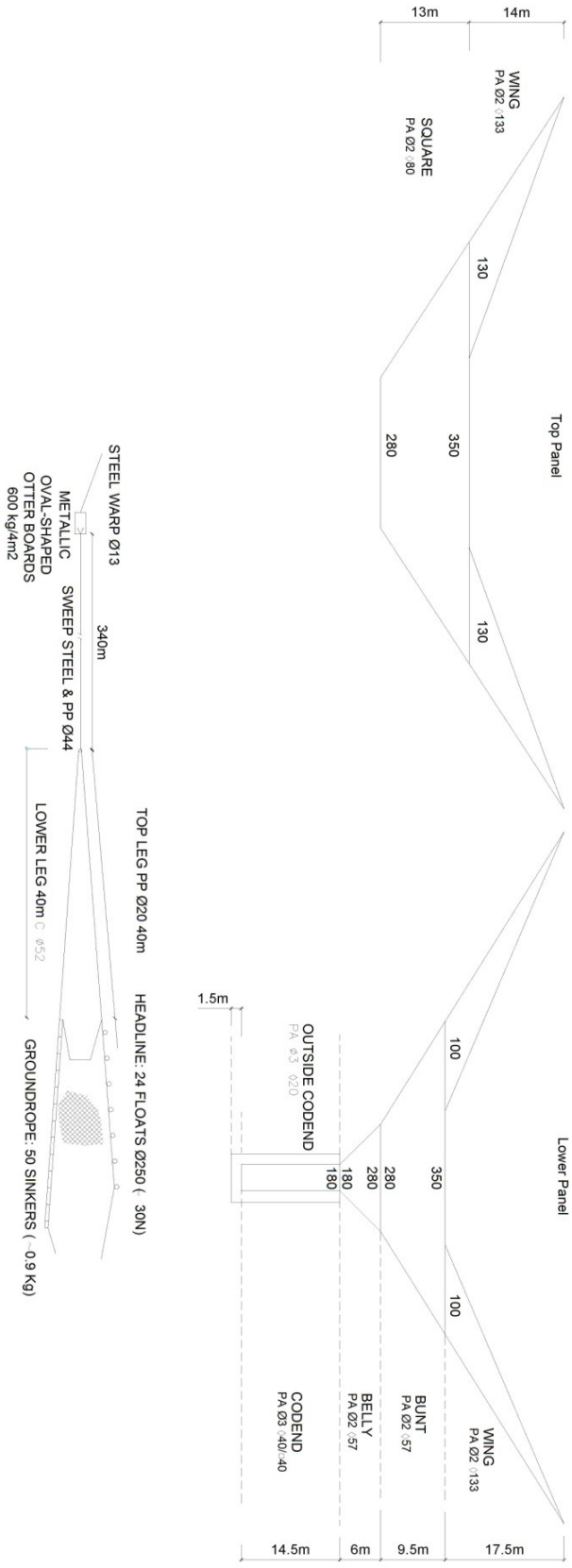
the Balearic Islands (Canals and Ballesteros, 1997; Massutí and Reñones, 2005). These benefits could be reached without diminishing the commercial yields for the most important target species or catch categories, with the only exception of *S. smaris*.

Further improvements in selectivity should be implemented in order to generalize to as much species as possible a true opportunity to spawn before getting caught. This *Let them spawn!* management strategy, would increase the resilience of stocks to overfishing (Myers and Mertz, 1998; Froese, 2004). In a multi-species bottom trawl fishery such as the one in the Balearic Islands continental shelf, this objective may represent a complicated, but necessary challenge in order to move forward to an ecosystem-based management of fisheries. Trying to achieve a *Let them spawn!* strategy for all species may compromise the economic viability of the fishery due to the great diversity of commercial species, and their different shapes and sizes at first maturity, but at least, an effort should be made in order to avoid that the species managed in that way were an exception.

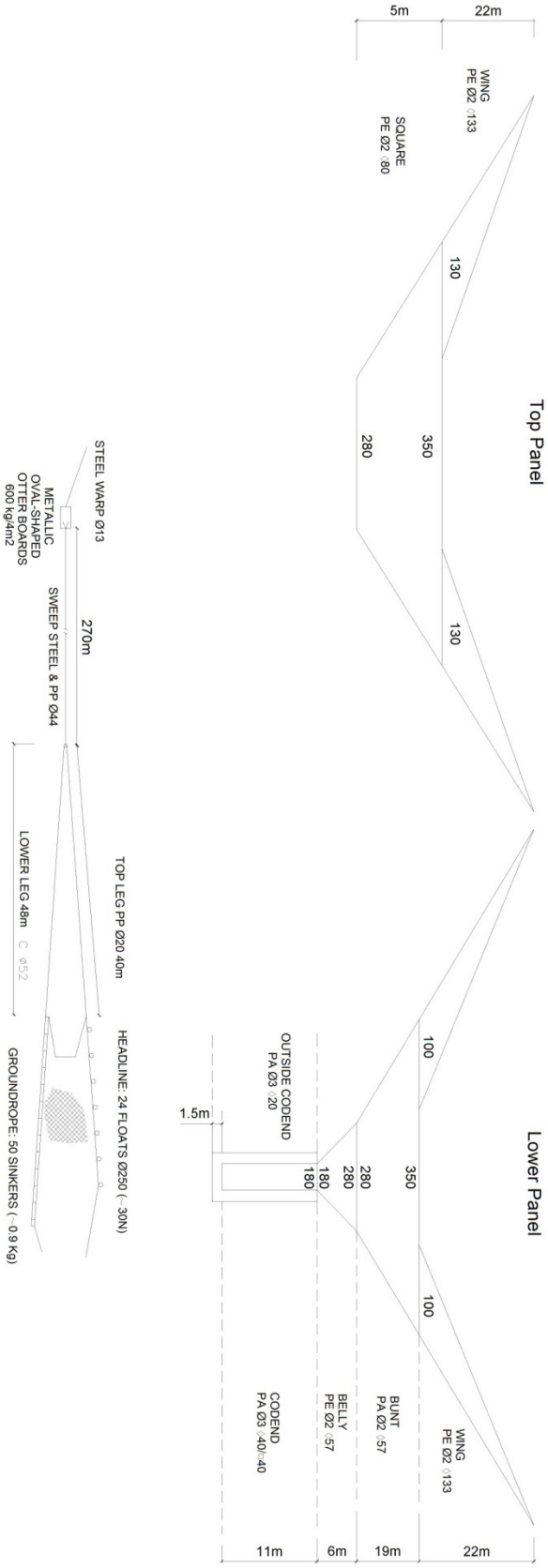
Table 5.4. Length at first capture (SL_{50}) using 40 mm square mesh codend, and length at first maturity (L_{50}) for species in Table 5.2. ^{pa} indicates proteandric species; ^{pg} protogynius species; *m* indicates that the length value, instead of the L_{50}, refers to the minimum length at which maturity was observed for that particular species; $_M$: males; $_F$: females. Those species for which the use of the square mesh increased the SL_{50} over the L_{50} are indicated with bold characters

Species	SL_{50}	L_{50F}	L_{50M}	L_{50T}	Source
Shallow shelf					
C. lastoviza	7.3			15.3	Chapter 4
M. surmuletus	12.2	16.8	15.0		Reñones et al. 1995
P. acarne	9.4		15.8^{pa}		Pajuelo and Lorenzo 2000
P. erythrinus	10.4	17.4^{pg}			Pajuelo and Lorenzo 1998
S. notata	**9.7**			**9.2**	Chapter 4
S. scrofa	8.3	15.4_m	17.7_m		Bradai and Bouain 1991
S. cabrilla	**14.1**			**14.8**	Chapter 4
S. smaris	**17.1**	**15.3^{pg}**			Dulcic et al. 2003
T. mediterraneus	**15.2**			**15**	Giannoulaki et al 2013
L. vulgaris	5.8	17.8	9.3		Uranga 2012
O. vulgaris	6	8.7_m	6.5_m		González et al 2011
Deep shelf					
A. cuculus	12.1			16.8	Chapter 4
C. linguatula	11.5	15.1	12.5		Vassilopoulou and Papaconstantinou 1994
H. dactylopterus	10.9	17.3_m	15.5_m		Muñoz et al. 2002
L. cavillone	**9.6**			**9.3**	Colloca et al 1997
M. merluccius	15.2			32.7	Oliver 1993
S. canicula	28.7	41	40		Ivory et al. 2004
T. draco	**18.1**			**14.4**	Chapter 4
E. cirhosa	6	9.5	7.5		Quetglas et al. unpublished

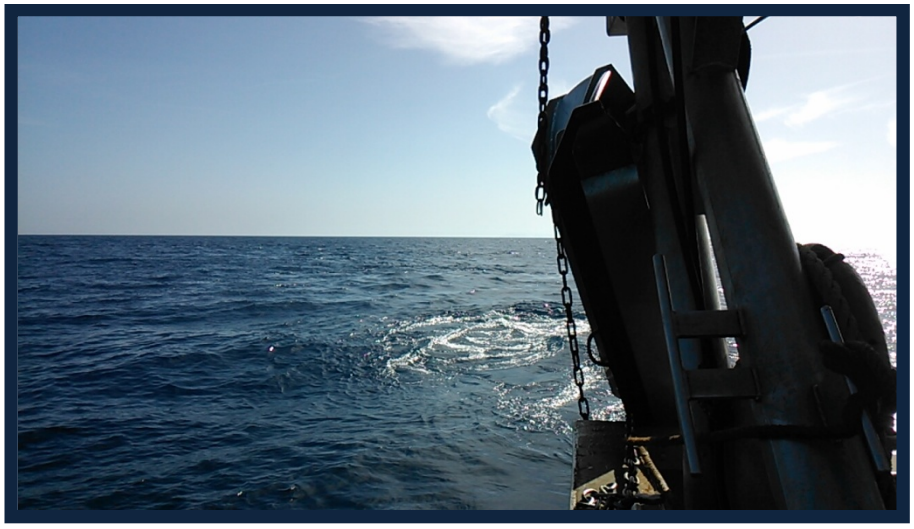
Annex 5.1. Schematic diagram of the commercial 'mallorquí'-type bottom trawl gear (PE, polyethylene; PA, polyamide; PP, polypropylene; ◊, diamond mesh; □ square mesh; ø, diameter).



Annex 5.2. Schematic diagram of the commercial 'quadrat'-type bottom trawl gear (PE, polyethylene; PA, polyamide; PP, polypropylene; ◊, diamond mesh; □ square mesh; ø, diameter).



CONCLUSIONS



Conclusions

1. The bottom trawl fishery developed on the continental shelf off the Balearic Islands represents an important percentage of the catches (28%) and the economic yield (25%) of the commercial fishing activities of the Archipelago. There have been identified and characterized several assemblages of macro-epibenthic organisms exploited by the bottom trawl fishery, which are distributed on the shallow shelf, between 50 and 90 m of depth, and the deep shelf, between 90 and 250 m. The presence of macro-algae is the most important factor explaining the differences between the benthic habitats of these two bathymetric strata.

2. In the Menorca Channel, the maërl beds, considered a sensitive habitat, predominate between 50 and 75 m of depth. They are dominated by Corallinaceae red algae and show a high biomass of macro-epibenthic organisms (around 1200 kg/km^2). Southwards of Menorca and Mallorca, the soft red algae beds predominate, which are distributed down to depths of 80 m. They are dominated by algae of the Peyssonneliaceae family, and show the highest macro-epibenthic biomasses of the continental shelf of the Balearic Islands (>8000 kg/km^2) and a macro-fauna species richness similar to that of the maërl beds, and even higher in the case of echinoderms, dominated by the irregular sea urchin *Spatangus purpureus*, and fish. The rest of the shallow shelf is dominated by sandy bottoms with low algae biomass that show the lowest macro-epibenthic biomass in this bathymetric stratum (around 200 kg/km^2). In the deep shelf there can be found the crinoid beds, in which the main macro-epibenthic species are *Leptometra phalangium* and also the sea urchins of the genus *Echinus*. These beds, considered an essential fish habitat for some fishing resources, have been detected in the south of Mallorca, the north of the Menorca Channel, and the east of Menorca, and show the highest biomass of macro-epibenthic organisms in this bathymetric stratum, around 700 kg/km^2. The detritic sandy-mud bottoms, dominated by the holothuria *Stichopus regalis*, and sometimes *Echinus* spp as well, predominate in the rest of the deep shelf, but showing a much lower macro-epibenthic biomass (55-140 kg/km^2).

3. In the coastal shelf, most of the fishing resources (12 out of the 16 species analyzed) are more abundant in red algae beds (maërl and *Peyssonnelia* beds) than in sandy bottoms. They are some of the main resources, in terms of biomass and economic value, of the landings of the bottom trawl fishery, such as the cephalopod *Octopus vulgaris* and the fish *Spicara smaris* and *Mullus surmuletus*. In the deep shelf, half of the fishing resources are more abundant in crinoid beds, although the most important resource, the fish *Merluccius merluccius*, is more abundant in sandy-mud bottoms than in crinoid beds.

4. The hydrodynamics affect the distribution of the macro-epibenthic assemblages in the coastal shelf of Mallorca. Whereas depth determines the vertical distribution of these species, the velocity of the marine currents has allowed explaining their horizontal distribution within the same bathymetric range. The currents from the northeast to the southwest predominate in the east coast of Mallorca where they show their maximum velocity in the Menorca Channel (~4.2 cm/s), and slow down to the south until reaching the most

sheltered area, the southwest of Mallorca, which shows the minimum values (~0.4 cm/s). This hydrodynamics gradient causes a gradient of macro-epibenthic communities, with dominance of rodolith (forming the maërl beds) in the Menorca Channel, and soft red algae, mainly Peyssonneliaceae, in the south of Mallorca.

5. The type of habitat and the hydrodynamics also influence the distribution of the nekto-benthic icthyofauna of the shelf and, particularly, its size structure. Juvenile individuals, or small-sized species, are more abundant in areas with lower hydrodynamism in the south Mallorca and in *Peyssonnelia* beds, which play an important role in the recruitment of some species and the support of small-sized species. The adults and the species of larger size are more abundant in the maërl beds of the Menorca Channel, with higher hydrodynamism.

6. These habitats not only affect the abundance of the fishing resources, but also their physiological condition and some biological parameters. *Scorpaena notata*, *Serranus cabrilla* and *Trigloporus lastoviza* are more abundant and show a better somatic condition in red algae beds than in sandy bottoms, with low algae biomass. Individuals of *S. notata* living in these algae bottoms, show a higher instantaneous growth rate than the whole population (0.237 and 0.216 years^{-1}, respectively). The spawning individuals of *S. cabrilla* and *T. lastoviza* living in maërl beds show a higher lipid content in their liver, moreover, the gonad of *S. cabrilla* show higher lipid content in both red algae beds, maërl and *Peyssonnelia*, than in sandy bottoms. In especially oligotrophic areas such as the Balearic Islands, the red algae bottoms of the continental shelf are essential habitats for the development of the vital cycle of nekto-benthic fish populations.

7. The mixed fish commercial category known as “Moralla”, in which up to sixty osteichthyan fish species are gathered, has a great importance for the bottom trawl fishery of the Balearic Islands. Its catches (140 t/year) are similar or even higher to those of species considered to be the target or this fishery in the continental shelf bottoms: e.g. *S. smaris* (~150 t/year), *M. surmuletus* (~90 t/year) and *Merluccius merluccius* (~80 t/year). The main population parameters (spawning season, length at first maturity, length-weight relationship and the von Bertalanffy growth function) of four of the most important species gathered in the “Morralla”, *S. cabrilla*, *T. lastoviza*, *Chelidonichthys cuculus* and *Trachinus draco*, which represent more than the 50% of this commercial category, have been estimated. This information along with the data collected during the monitoring of the fishery, have allowed assessing for the first time these fishing resources. The pseudo-cohort analysis and the yield per recruit analysis, show a situation of growth overfishing for all these species. The reduction of the fishing effort required to achieve the maximum sustainable yield has been estimated around the 70%, even higher than that for *M. surmuletus* (53%), one of the target species of the bottom trawl fishing in the coastal shelf, which is assessed yearly. The results obtained set out the need to include the monitoring and assessment of by-catch species in the management of multi-species fisheries, such as the bottom trawl fishery of the shelf of the Balearic Islands.

8. On the other hand, some population parameters of *S. cabrilla*, *T. lastoviza*, *C. cuculus* and *T. draco*, estimated from fishery independent information obtained from the MEDITS scientific surveys, show stability or even some recovering of the population of these species. No trend was detected for their abundance, biomass, or distribution range during the period 2001-2011, and the proportion of 'large' individuals (>½L_∞) in relation to their average abundance during the first three years of this period, shows an increasing trend. This improvement coincides with the displacement to the slope of the effort exerted by the bottom trawl fleet, where its most valued resource, the red shrimp (*Aristeus antennatus*), is found. Hence, although the studied species are overexploited, the reduction of the bottom trawl effort in the continental shelf would have allowed some improvement of their populations.

9. The change of mesh geometry in the 40 mm mesh codend of the bottom trawl nets, from diamond to square, reduces the discard (mainly of soft red algae, whose yields decrease from 80 to 20 kg/30 min) and the catches of immature individuals and of individuals under the minimum landing size, of most of species including target and by-catch ones. This improvement in the selectivity is obtained without a decrease of the yields, with the exception of the picarel (*S. smaris*). However, this improvement is not effective for all the species, given that it does not allow the escapement of some invertebrates (e.g. sponges and ascidians), immature individuals of osteichthyan fish (e.g. *Lophius* spp.) and chondrichthyans (e.g. batoids). Moreover, the size at first capture only increases to values close to, or higher than, the size at first maturity for 6 out of the 19 commercial species analyzed, even remaining, in some cases, below the minimum landing size. The direct physical impact of the bottom trawl gear on the sea floor is not reduced either.

10. The populations of the main species exploited by the bottom trawl fishery developed in the continental shelf of the Balearic Islands show overexploitation symptoms. The improvement and sustainability of these populations of marine living resources, and hence of the bottom trawl fishery, will not only depend on the implementation of management measures focused on the improvement of the current exploitation regime. The relationship between key stages of the vital cycle of the fishing resources and the benthic habitats where they develop, and the conservation of these habitats, will have to be taken into account as well. Some of these habitats are particularly sensitive to anthropogenic impacts, such as fishing activities, and because of it, they have been classified as protected habitats in the fishing regulation, whereas others are essential for the development of the fishing resources. The loss and fragmentation of the red algae beds, could have consequences beyond a decrease of the abundance of the associated nekto-benthic fish species, it could also cause a decrease of the resilience of their populations and an increase of their vulnerability.

Conclusions

1. La pesquera de ròssec que es desenvolupa a la plataforma continental de les Illes Balears representa un percentatge important de les captures (28%) i el rendiment econòmic (25%) de la pesca professional que es realitza a l'Arxipèlag. S'han identificat i caracteritzat diverses associacions d'organismes macro-epibentònics explotats per la pesca de ròssec, que es distribueixen en la plataforma costanera, entre 50 i 90 m de fondària, i la plataforma profunda, entre 90 i 250 m. La presència de macro-algues és el factor més important a l'hora d'explicar les diferències entre els hàbitats bentònics d'aquests dos estrats batimètrics.

2. En el Canal de Menorca, entre 50 i 75 m de profunditat, hi predominen els fons de maërl, d'algues vermelles coral·linàcies, que mostren una elevada biomassa d'organismes macro-epibentònics (entorn de 1200 kg/km^2) i que són considerats un hàbitat sensible. Al sud de Menorca i Mallorca hi predominen fons d'algues vermelles toves, que es distribueixen fins a 80 m de fondària. Hi dominen les algues de la família Peyssonneliaceae, i presenten les biomasses macro-epibentòniques més elevades de la plataforma continental de les Illes Balears (>8000 kg/km^2) i una riquesa específica de macro-fauna semblant a la dels fons de maërl, i inclús superior en el cas dels equinoderms, dominats per l'eriçó irregular *Spatangus purpureus*, i els peixos. A la resta de la plataforma costanera hi predominen fons de sorra amb poca biomassa algal, que presenten les menors biomasses macro-epibentòniques d'aquest estrat batimètric (200 kg/km^2). A la plataforma profunda s'hi troben els fons de crinoïdeus, on les principals espècies macro-epibentòniques són *Leptometra phalangium* i també eriçons del gènere *Echinus*. Aquests fons, considerats com a hàbitat essencial per alguns recursos pesquers, s'han identificat al sud de Mallorca, al nord del Canal de Menorca i a l'est de Menorca, i presenten les biomasses d'organismes macro-epibentònics més elevades d'aquest estrat batimètric, al voltant dels 700 kg/km^2. A la resta de la plataforma profunda hi predominen fons de sorra i fang detrítics, dominats per l'holotúria *Stichopus regalis*, i en alguns casos també per *Echinus* spp., amb biomasses macro-epibentòniques molt menors (55-140 kg/km^2).

3. En la plataforma costanera, la majoria dels recursos pesquers (12 de les 16 espècies analitzades) són més abundants en fons d'algues vermelles (maërl i *Peyssonnelia*) que en fons de sorra. Són alguns dels principals recursos, en termes de biomassa i valor econòmic, de les captures desembarcades de la pesquera de ròssec, com el cefalòpode *Octopus vulgaris* i els peixos *Spicara smaris* i *Mullus surmuletus*. En la plataforma profunda, la meitat dels recursos pesquers són més abundants als fons de crinoïdeus, malgrat que el principal recurs, el peix *Merluccius merluccius*, és més abundant en fons de sorra i fang que en fons de crinoïdeus.

4. La hidrodinàmica afecta la distribució de les associacions d'organismes macro-epibentònics de la plataforma costanera de Mallorca. Mentre que la fondària determina la distribució vertical d'aquestes espècies, la velocitat dels corrents marins ha permès explicar la seva distribució horitzontal dins un mateix rang batimètric. A la costa est de Mallorca, predominen els corrents del nord-est al sud-oest amb velocitats màximes al Canal de Menorca (~4.2 cm/s),

que van disminuint cap al sud fins a la zona més arrecerada, el sud-oest de Mallorca, amb valors mínims (~0.4 cm/s). Aquest gradient hidrodinàmic determina un gradient de les comunitats macro-epibentòniques, amb predominança de rodolits, que conformen els fons de maërl, al Canal de Menorca, i d'algues vermelles toves, principalment *Peyssonnelia*, al sud de Mallorca.

5. El tipus d'hàbitat i la hidrodinàmica també influeixen en la distribució de la ictiofauna necto-bentònica de plataforma i, especialment, en la seva estructura de talles. Els individus juvenils, o d'espècies de mida petita, són més abundants a les zones amb menor hidrodinamisme del sud de Mallorca i en fons de *Peyssonnelia*, els quals juguen un paper important en el reclutament d'algunes espècies i en el manteniment de les poblacions d'espècies de mida petita. Els adults i les espècies de mida més grossa són més abundants en fons de maërl del Canal de Menorca, amb major hidrodinamisme.

6. Aquests hàbitats no només poden influir en l'abundància dels recursos pesquers, sinó també en la seva condició fisiològica i en alguns paràmetres biològics. *Scorpaena notata, Serranus cabrilla* i *Trigloporus lastoviza* són més abundants i presenten una millor condició somàtica en fons d'algues vermelles que en fons de sorra, amb poca biomassa algal. Els individus de *S. notata* que viuen en aquests fons d'algues, presenten una taxa de creixement instantània més elevada que el conjunt de tota la població (0.237 i 0.216 anys^{-1}, respectivament). Els individus en posta de *S. cabrilla* i *T. lastoviza* que viuen en fons de maërl presenten major contingut lipídic en fetge, a demés, la gònada de *S. cabrilla* presenta major contingut lipídic a ambdós fons d'algues vermelles, maërl i *Peyssonnelia*, que a fons de sorra. En àrees especialment oligotròfiques com les Illes Balears, els fons d'algues vermelles de la plataforma continental són hàbitats essencials pel desenvolupament del cicle vital de les poblacions de peixos necto-bentònics.

7. La categoria comercial 'Morralla', on s'hi agrupen fins a seixanta espècies de peixos osteïctis, és de gran importància per a la pesca de ròssec de les Illes Balears. Les seves captures (~140 t/any) són semblants o inclús superiors a les d'espècies considerades l'objectiu d'aquesta pesquera en fons de la plataforma continental: p.ex. *S. smaris* (~150 t/any), *M. surmuletus* (~90 t/any) i *Merluccius merluccius* (~80 t/any). S'han estimat els principals paràmetres poblacionals (època de posta, talla de primera maduresa, relació talla-pes i corba de creixement de von Bertalanffy) de quatre de les principals espècies que formen part de la 'Morralla', *S. cabrilla*, *T. lastoviza*, *Chelidonichthys cuculus* i *Trachinus draco*, les quals representen més del 50% d'aquesta categoria comercial. Aquesta informació, juntament amb dades provinents del seguiment de la pesquera, ha permès avaluar per primera vegada aquests recursos pesquers. L'anàlisi de pseudocohorts pels anys 2008-2010, i l'anàlisi de rendiment per recluta, mostren una situació de sobrepesca de creixement per a totes aquestes espècies. La reducció de l'esforç de pesca que es requereix per assolir el rendiment màxim sostenible s'ha estimat al voltant del 70%, major inclús que per *M. surmuletus* (53%), una de les espècies objectiu de la pesca de ròssec en la plataforma costanera, que com a tal s'avalua anualment. Els resultats obtinguts plantegen la necessitat d'incorporar el monitoratge i l'avaluació d'espècies 'by-catch' en la gestió de les pesqueres

multiespecífiques, com és la pesquera de ròssec de plataforma de les Illes Balears, donat que les poblacions d'aquestes espècies poden trobar-se en nivells de sobreexplotació més pronunciats que els que presenten les espècies objectiu de la pesquera.

8. Per contra, alguns paràmetres poblacionals de *S. cabrilla*, *T. lastoviza*, *C. cuculus* i *T. draco*, estimats a partir d'informació independent de l'explotació pesquera, obtinguda de les campanyes d'investigació MEDITS, mostren estabilitat o, fins i tot, certa recuperació de les poblacions d'aquestes espècies. No s'han detectat tendències en la seva abundància, biomassa, ni rang de distribució durant el període 2001-2011 i la proporció d'individus 'grossos' ($>½L_{\infty}$) respecte a la seva abundància mitjana durant els primers tres anys d'aquest període, mostra una tendència ascendent. Aquesta millora coincideix amb el desplaçament de l'esforç pesquer de la flota de ròssec cap al talús, on hi troba el seu recurs més valuós, la gamba vermella (*Aristeus antennatus*). Per això, tot i la situació de sobrepesca en què es troben les espècies estudiades, la reducció de l'esforç de ròssec en la plataforma continental hauria permès una certa millora de les seves poblacions.

9. El canvi de la geometria de la malla al cop de les xarxes de ròssec, de ròmbica a quadrada de 40 mm, redueix el rebuig (principalment d'algues vermelles toves, els rendiments de les quals passen de 80 a 20 kg/30 min) i les captures d'individus immadurs i de talles petites no comercialitzables, de la majoria d'espècies tan objectiu com 'by-catch'. Aquesta millora en la selectivitat s'obté sense una disminució dels rendiments, exceptuant el cas del gerret (*S. smaris*). Tot i així, aquesta millora no és efectiva per a totes les espècies, donat que segueix sense permetre l'escapament d'alguns invertebrats (p.ex. esponges i ascidis), individus immadurs de peixos osteïctis (p.ex. *Lophius* spp.) i condrictis (p.ex. batoids). A més, la talla de primera captura només s'incrementa fins valors pròxims o superiors a la talla de primera maduresa per a 6 de les 19 espècies comercials analitzades, fins i tot quedant, en alguns casos, per davall de la talla mínima legal. Tampoc es disminueix l'impacte físic directe que exerceix l'art de ròssec sobre el fons marí.

10. Les poblacions de les principals espècies explotades per la pesca de ròssec que es desenvolupa en la plataforma continental de les Illes Balears mostren símptomes de sobrepesca. La millora i sostenibilitat d'aquests recursos marins vius, i per tant de la pesca de ròssec, no només dependrà de la implementació de mesures de gestió que corregeixin el règim d'explotació actual. També s'haurà de tenir en compte la relació entre aspectes clau del cicle vital dels recursos pesquers i els hàbitats bentònics on es desenvolupen, així com la conservació d'aquests hàbitats. Alguns d'ells són especialment sensibles als impactes antròpics, entre aquests la pesca, i per això han estat catalogats a la normativa pesquera com a hàbitats protegits, mentre d'altres són essencials pel desenvolupament dels recursos pesquers. La pèrdua i fragmentació dels fons d'algues vermelles, podria tenir conseqüències més enllà d'una davallada de l'abundància d'espècies de peixos necto-bentònics que s'hi troben associades, també provocaria una disminució en la resiliència de les seves poblacions i un augment de la seva vulnerabilitat.

Cited references

Abella A., Caddy J.F., Serena F. (1997). Do natural mortality and availability decline with age? An alternative yield paradigm for juvenile fisheries, illustrated by the hake *Merluccius merluccius* fishery in the Mediterranean. *Aquatic Living Resources* 10: 257-269.

Acosta A., Canals M., López-Martínez J., Muñoz A., Herranz P., Urgeles R., Palomo C., Casamor J.L. (2002). The Balearic Promontory geomorphology (western Mediterranean): morphostructure and active processes. *Geomorphology* 49: 177-204.

Aldebert Y., Recasens L. (1996). Comparison of methods for stock assessment of European hake *Merluccius merluccius* in the Gulf of Lions (Northwestern Mediterranean). *Aquatic Living Resources* 9: 13-22.

Aller J.Y. (1989). Quantifying sediment disturbance by bottom currents and its effect on benthic communities in a deep-sea western boundary zone. *Deep-Sea Research* 36: 901-934.

Anderson T.J. (1997). Habitat selection and shelter use by *Octopus tetricus*. *Marine Ecology Progress Series* 150: 137-148.

Ardizzone G.D. (2006). An introduction to Sensitive and Essential Fish Habitats identification and protection in the Mediterranean Sea. Working Document to the STECF/SGMED-06-01 sub-group meeting on Sensitive and Essential Fish Habitats in the Mediterranean, Rome.

Auster P.J, Langton R.W. (1999). The effects of fishing on fish habitat. *American Fisheries Society Symposium* 22: 150-187.

Bagge O. (2004). The biology of the greater weever (*Trachinus draco*) in the commercial fishery of the Kattegat. *ICES Journal of Marine Science* 61: 933-943.

Bahamon N., Sardà F., Suuronen P. (2006). Improvement of trawl selectivity in the NW Mediterranean demersal fishery by using a 40 mm square mesh codend. *Fisheries Research* 81: 15-25.

Ballesteros E. (1988). Composición y estructura de los fondos de maërl de Tossa de Mar (Girona, España). *Collectanea Botanica* 17: 161-182.

Ballesteros E. (1992). Els fons rocosos profunds amb *Osmundaria volubilis* (Linné) R.E. Norris a les Balears. *Bolletí de la Societat de Història. Natural de les Illes Balears* 35: 33-50.

Ballesteros E. (1994). The deep-water *Peyssonnelia* beds from the Balearic Islands (western Mediterranean). *Marine Ecology-Pubblicazioni Della Stazione Zoologica di Napoli I* 15: 233-253.

Ballesteros E. (2006). Mediterranean coralligenous assemblages: a synthesis of present knowledge. *Oceanography and Marine Biology: An Annual Review* 44: 123-195.

Barbera C., Bordehore C., Borg J.A., Glémarec M., Grall J., Hall-Spencer J.M., De la Huz C.H., Lanfranco E., Lastra M., Moore P.G., Mora J., Pita M.E., Ramos-Esplá A., Rizzo M., Sánchez-Mata A., Seva A., Schembri P.J., Valle C. (2003). Conservation and management of northeast Atlantic and Mediterranean maerl beds. *Aquatic Conservation: Marine Freshwater Ecosystems* 13: S65-S76.

Barberá C., Moranta J., Ordines F., Ramón M., de Mesa A., Díaz-Valdés M., Grau A.M., Massutí E. (2012). Biodiversity and habitat mapping of Menorca Channel (western Mediterranean): implications for conservation. *Biodiversity and Conservation* 21: 701-728.

Basso D. (1998). Deep rhodolith distribution in the Pontian Islands, Italy: a model for the palaeoecology of a temperate sea. *Palaeogeography, Palaeoclimatology, Palaeoecology* 137: 173-187.

Baynes T.W., Szmant A.M. (1989). Effect of current on the sessile benthic community structure of an artificial reef. *Bulletin of Marine Science* 44: 545-566.

Ben Jrad L., Fehri-Bedoui R., Ben Slama S., Ben Hassine O.K. (2010). Reproduction et régime alimentaire de *Trigloporus lastoviza* (Triglidae) dans le golfe de Tunis (Méditerranée occidentale). *Cybium* 34: 353-365.

Benaka L.R. (1999). Fish habitat: essential fish habitat and rehabilitation. Symposium 22: Proceedings of the Sea Grant symposium. American Fisheries Society, Bethesda, Maryland.

Bergman M.J.N., van Santbrink J.W. (2000). Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. *ICES Journal of Marine Science* 57: 1321-1331.

Berrill N.J. (1950). The Tunicata. With an account of the British species. The Ray Society, London.

Bertrand J.A., Gil de Sola L., Papaconstantinou C., Relini G., Souplet A. (2002). The general specifications of the MEDITS surveys. *Scientia Marina* 66: 9-17.

Biagi F., Sartor P., Ardizzone G.D., Belcari P., Belluscio A., Serena F. (2002). Analysis of demersal assemblages off Tuscany and Latium coasts (north-western Mediterranean). *Scientia Marina* 66: 233-242.

Bianchi C.N., Morri C. (2000). Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. *Marine Pollution Bulletin* 40: 367-376.

Bianchi G. (1991). Demersal assemblages of the continental shelf and slope edge between the Gulf of Tehuantepec (Mexico) and the Gulf of Papagayo (Costa Rica). *Marine Ecology Progress Series* 73: 121-140.

Bordehore C., Ramos-Esplá A.A., Riosmena-Rodríguez R. (2003). Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula. *Aquatic Conservation: Marine Freshwater Ecosystems* 13: 43-54.

Bosc E., Bricaud A., Antoine D. (2004). Seasonal and interannual variability in algal biomass and primary production in the Mediterranean Sea, as derived from 4 years of SeaWiFS observations. *Global Biogeochemical Cycles* 18: GB1005.

Botsford L.W., Castilla J.C., Peterson C.H. (1997). The management of fisheries and marine ecosystems. *Science* 277: 509-515.

Boudaya L., Neifar L., Rizzo P., Badalucco C., Bouain A., Fiorentino F. (2010). Age and growth of *Chelidonichthys lastoviza* (Bonnaterre, 1788) in Tunisia. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 39: 458.

Boudaya L., Neifar L., Taktak A., Ghorbel M., Bouain A. (2007). Diet of *Chelidonichthys obscurus* and *Chelidonichthys lastoviza* (Pisces: Triglidae) from the Gulf of Gabes (Tunisia). *Journal of Applied Ichthyology* 23: 646-653.

Bradai M.N., Bouain A. (1990)a. Age et croissance de *Scorpaena notata* (Rafinesque, 1810) dans le Golfe de Gabes (Tunisie). *Bulletin Institut National des Sciences et Technologies de la Mer, Salambo* 17: 35-46.

Bradai M.N., Bouain A. (1990)b. Régime alimentaire de *Scorpaena porcus* et de *S. scrofa* (Teleostei, Scorpaenidae) du Golfe de Gabes, Tunisie. *Cybium* 14: 207-216.

Bradai M.N., Bouain A. (1991). Reproduction de *Scorpaena porcus* (Linné, 1758) et de *S. scrofa* (Linné 1758) (Pisces, Scorpaenidae) du Golfe de Gabes. *Oebalia* 12: 167-180.

Bradford M.M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry* 72: 248-254.

Broadhurst M. K., Suuronen P., Hulme A. (2006). Estimating collateral mortality from towed fishing gear. *Fish and Fisheries* 7: 180-218.

Brody L.R., Nestor M.J.R. (1985). Regional forecasts for the Mediterranean basin. *Technical report No. 80-10*. Naval Environmental Prediction Research Facility, Monterey, California, USA.

Browman H.I., Stergiou K.I. (2004). Perspectives on ecosystem based approaches to the management of marine resources. *Marine Ecology Progress Series* 274: 269-303.

Brown-Peterson N.J., Wyanski D.M., Saborido-Rey F., Macewicz B.J., Lowerre-Barbieri S.K. (2011). A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 3: 52-70.

Bunnell D.B., Thomas S.E., Stein R.A. (2007). Prey resources before spawning influence gonadal investment of female, but not male, white crappie. *Journal of Fish Biology* 70: 1838-1854.

Caddy J.F. (1991). Death rates and time intervals: Is there an alternative to the constant natural mortality axiom?. *Reviews in Fish Biology and Fisheries* 1: 109-138.

Caddy J.F. (1993). Some future perspectives for assessment and management of Mediterranean fisheries. *Scientia Marina* 57: 121-130.

Campos A., Fonseca P., Henriques V. (2003). Size selectivity for four fish species of the deep groundfish assemblage off the Portuguese southwest coast: evidence of mesh size, mesh configuration and cod end catch effects. *Fisheries Research* 63: 213-233.

Canals M., Ballesteros E. (1997). Production of carbonate particles by phytobenthic communities on the Mallorca-Menorca shelf, northwestern Mediterranean Sea. *Deep-sea Research Part II-Topical Studies in oceanography* 44: 611-629.

Carbonell A., Alemany F., Merella P., Quetglas A., Román E. (2003). The by-catch of sharks in the western Mediterranean (Balearic Islands) trawl fishery. *Fisheries Research* 61: 7-18.

Carbonell A., Carbonell M., Demestre M., Grau A., Monserrat M. (1999). The red shrimp *Aristeus antennatus* (Risso, 1816) fishery and biology in the Balearic Islands, Western Mediterranean. *Fisheries Research* 44: 1-13.

Carbonell A., Martín P., De Ranieri S., WEDIS team. (1998). Discards of the western Mediterranean trawl fleets. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 35: 392-393.

Carney R.S. (2005). Zonation of deep biota on continental margins. *Oceanography and Marine Biology* 43: 211-278.

Carr M.H. (1989). Effects of macroalgal assemblages on the recruitment of temperate zone reef fishes. *Journal of Experimental Marine Biology and Ecology* 126: 59-76.

Choat J.H., Ayling A.M. (1987). The relationship between habitat structure and fish faunas on New Zealand reefs. *Journal of Experimental Marine Biology and Ecology* 110: 257-284.

Clarke K.R., Warwick R.M. (1994). Changes in Marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, Plymouth.

Coleman F.C., Williams S.L. (2002). Overexploiting marine ecosystem engineers: potential consequences for biodiversity. *Trends in Ecology and Evolution* 17: 40-44.

Coll M., Cury P., Azzurro E., Bariche M., Bayadas G., Bellido J.M., Chaboud C., Claudet J., El-Sayed A.-F., Gascuel D., Knittweis L., Pipitone C., Samuel-Rhoads Y., Taleb S., Tudela S., Valls A (2013). The scientific strategy needed to promote a regional ecosystem-based approach to fisheries in the Mediterranean and Black Seas. *Reviews in Fish Biology and Fisheries* 23: 1-14.

Colloca F., Cardinale M., Ardizzone G.D. (1997). Biology, spatial distribution and population dynamics of *Lepidotrigla cavillone* (Pisces: Triglidae) in the central Tyrrhenian Sea. *Fisheries Research* 32: 21-32.

Colloca F., Cardinale M., Belluscio A., Ardizzone G.D. (2003)a. Structure and diversity of demersal assemblages in the central Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 56: 469-480.

Colloca F., Cardinale M., Marcello A., Ardizzone G.D. (2003)b. Tracing the life history of red gurnard (*Aspitrigla cuculus*) using validated otolith annual rings. *Journal of Applied Ichthyology* 19: 1-9.

Colloca F., Carpentieri P., Balestri E., Ardizzone G.D. (2004). A critical habitat for Mediterranean fish resources: shelf-break areas with *Leptometra phalangium* (Echinodermata: Crinoidea). *Marine Biology* 145: 1129-1142.

Connell S.D., Jones G.P. (1991). The influence of habitat complexity on post-recruitment processes in a temperate reef fish population. *Journal of Experimental Marine Biology and Ecology* 151: 271-294.

Crossin G.T., Hinch S.G. (2005). A nonlethal, rapid method for assessing the somatic energy content of migrating adult Pacific salmon. *Transactions of the American Fisheries Society* 134: 184-191.

Davidson D., Marshall C.T. (2010). Are morphometric indices accurate indicators of stored energy in herring *Clupea harengus*? *Journal of Fish Biology* 76: 913-929.

De Biasi A.M. (2004). Impact of trawling on the benthic assemblage along the Tuscany coast (north Tyrrhenian Sea, Italy). *ICES Journal of Marine Science* 61: 1260-1266.

De Buen F. (1934). Primera campaña biológica a bordo del "Xauen" en aguas de Mallorca. In: De Buen F. (Editor), Trabajos, pp. 7-72. Instituto Español de Oceanografía, Madrid.

Demestre M., Lleonart J. (1993). Population dynamics of *Aristeus antennatus* (Decapoda: Dendrobranchiata) in the northwestern Mediterranean. *Scientia Marina* 57: 183-189.

Demestre M., Sánchez P., Abelló P. (2000). Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-western Mediterranean. *Journal of the Marine Biological association of the United Kingdom* 80: 981-988.

Depczynski M., Bellwood D.R. (2005). Wave energy and spatial variability in community structure of small cryptic coral reef fishes. *Marine Ecology Progress Series* 303: 283-293.

Dhargalkar V.K., Burton H.R., Kirkwood J.M. (1988). Animal associations with the dominant species of shallow water macrophytes along the coastline of the Vestfold Hills, Antarctica. *Hydrobiologia* 165: 141-150.

Dietrich D.E. (1997). Application of a modified Arakawa 'A' grid ocean model having reduced numerical dispersion to the Gulf of Mexico circulation. *Dynamics of Atmospheres and Oceans* 27: 201-217.

Donnan D.W., Moore P.G. (2003)a. Special issue: International Workshop on the conservation and management of maërl- Introduction. *Aquatic Conservation: Marine Freshwater Ecosystems* 13: S1-S3.

Donnan D.W., Moore P.G. (2003)b. Special issue: International Workshop on the conservation and management of maërl- Conclusions. *Aquatic Conservation: Marine Freshwater Ecosystems* 13: S77-S78.

Dulčić J., Pallaoro A., Cetinić P., Kraljević M., Soldo A., Jardas I. (2003). Age, growth and mortality of picarel, *Spicara smaris* L. (Pisces: Centracanthidae), from the eastern Adriatic (Croatian coast). *Journal of Applied Ichthyology* 19: 10-14.

Dutil J.D., Lambert Y. (2000). Natural mortality from poor condition in Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Sciences* 57: 826-836.

Düzbastilar F.O., Aydin C., Metin G., Lök A., Ulaş A., Özgül A., Gül B., Metin C., Özbilgin H., Şensurat T., Tokaç A. (2010)a. Survival of fish after escape from a 40 mm stretched diamond mesh trawl codend in the Aegean Sea. *Scientia Marina* 74: 755-761.

Düzbastilar F.O., Özgül A., Aydin I., Gül B., Soykan O. (2010)b. A Preliminary Study on the Survival of Brown Comber, *Serranus Hepatus* (Actinopterygii, Perciformes, Serranidae), Escaping from the Codend of a Bottom Trawl. *Acta Ichthyologica Et Piscatoria* 40: 27-36.

Edgar G.J., Shaw C. (1995). The production and trophic ecology of shallow-water fish assemblages in southern Australia .1. Species richness, size-structure and production of fishes in Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* 194: 53-81.

Ehrich S., Stelzenmüller V., Adlerstein S. (2009). Linking spatial pattern of bottom fish assemblages with water masses in the North Sea. *Fisheries Oceanography* 18: 36-50.

Ellis J.R., Rogers S.I., Freeman S.M. (2000). Demersal assemblages in the Irish Sea, St George's Channel and Bristol Channel. *Estuarine, Coastal and Shelf Science* 51: 299-315.

Emery W.J., Thomson R.E. (1998). *Data Analysis Methods in Physical Oceanography*. Elsevier. Amsterdam.

Emig C.C. (1987). Offshore brachiopods investigated by submersible. *Journal of Experimental Marine Biology and Ecology* 1080: 261-273.

Engel J., Kvitek R. (1998). Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. *Conservation Biology* 12: 1204-1214.

Estrada M. (1996). Primary production in the northwestern Mediterranean. *Scientia Marina* 60: 55-64.

EU (2008). Report of the Ad Hoc Meeting of independent experts on Indicators and associated data requirements to measure the impacts of fisheries on the marine ecosystem. Commission Staff Working Paper.

Everett R.A. (1994). Macroalgae in marine soft-sediment communities: effects on benthic faunal assemblages. *Journal of Experimental Marine Biology and Ecology* 175: 253-274.

Farrugio H., Oliver P., Biagi F. (1993). An overview of the history, knowledge, recent and future research trends in Mediterranean fisheries. *Scientia Marina* 57: 105-119.

Fasola M., Canova L., Foschi F., Novell O., Bressan M. (1997). Resource use by a Mediterranean rocky slope fish assemblage. *Marine Ecology-Pubblicazioni Della Stazione Zoologica di Napoli I* 18: 51-66.

Fernandez V., Dietrich D.E., Haney R.L., Tintore J. (2005). Mesoscale, Seasonal and Interannual Variability in the Mediterranean Sea using the DieCAST Ocean Model. *Progress in Oceanography* 66: 321-340.

Fischer W., Bauchot M.L., Schneider M. (1987). *Fiches FAO d' identification des espèces pour les besoins de la pêche. (Révision 1). Méditerranée et mer Noire. Zone de pêche 37. Volume II. Vertébrés*. FAO. Rome.

Fogarty M.J. (1999). Essential habitat, marine reserves and fishery management. *Trends in Ecology and Evolution* 14: 133-134.

Folch J., Lees M., Sloane-Stanely G.H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *The Journal of Biological Chemistry* 226: 497-507.

Fornos J.J., Ballesteros E., Massuti C., Rodríguez-Perea A. (1988). Red algae sediments in the Balearic Shelf. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 31:2.

Fosså J. H., Mortensen P.B., Furevik D.M. (2002). The deep-water coral *Lophelia pertusa* in Norwegian waters?: distribution and fishery impacts. *Hydrobiologia* 471: 1-12.

Foster A.R., Houlihan D.F., Hall S.J. (1993). Effects of nutritional regime on correlates of growth-rate in juvenile Atlantic cod (*Gadus morhua*) - Comparison of morphological and biochemical measurements. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 502-512.

Foster M.S. (2001). Rhodoliths: between rocks and soft places. *Journal of Phycology* 37: 659-667.

Francour P., Le Direac'h L. (1994). Recrutement de l'ichtyofaune dans l'herbier superficiel à *Posidonia oceanica* de la réserve naturelle de Scandola (Corse, Méditerranée nord-occidentale): données préliminaires. *Travaux Scientifics du Parc National et Régional Réserve Corse* 46: 71-91.

Fredj G., Bellan-Santini D., Meinardi M. (1992). Etat des connaissances sur la faune méditerranéenne. *Bulletin de L'Institut Océanographique (Monaco)* 9: 133-145.

Froese R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries* 5: 86-91.

Fryer R.J. (1991). A model of between-haul variation in selectivity. *ICES Journal of Marine Science* 48: 281-290.

Fulton C.J., Bellwood D.R. (2002). Ontogenetic habitat use in labrid fishes: an ecomorphological perspective. *Marine Ecology Progress Series* 236: 255-262.

Gaertner J.C., Mazouni N., Sabatier R., Millet B. (1999). Spatial structure and habitat associations of demersal assemblages in the Gulf of Lions: a multicompartmental approach. *Marine Biology* 135: 199-208.

Garcia S.M., Zerbi A., Aliaume C., Do Chi T., Lasserre G. (2003). The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. *FAO Fisheries Technical Paper* 443: 1-71.

García-Díaz M.M., Tuset V.M., González J.A., Socorro J. (1997). Sex and reproductive aspects in *Serranus cabrilla* (Osteichthyes: Serranidae): macroscopic and histological approaches. *Marine Biology* 127: 379-386.

García-Rodríguez M., Esteban A. (1999). On the biology and fishery of *Aristeus antennatus* (Risso, 1816), (Decapoda, Dendrobranchiata) in the Ibiza Channel (Balearic Islands, Spain). *Scientia Marina* 63: 27-37.

García-Rodríguez M., Esteban A., Gil J.L.P. (2000). Considerations on the biology of *Plesionika edwardsi* (Brandt, 1851) (Decapoda, Caridea, Pandalidae) from experimental trap catches in the Spanish western Mediterranean Sea. *Scientia Marina* 64: 369-379.

García-Rubies A., Macpherson E. (1995). Substrate use and temporal pattern of recruitment in juvenile fishes of the Mediterranean littoral. *Marine Biology* 124: 35-42.

García-Rubies A., Zabala M. (1990). Effects of total fishing prohibition on the rocky fish assemblages of Medes island marine reserve (NW Mediterranean). *Scientia Marina* 54: 317-328.

GFCM (2001). Report of the twenty-sixth session, pp. 26-27. General Fisheries Commission for the Mediterranean Report.

GFCM (2012). Report of the fourteenth session of the Scientific Advisory Committee. FAO Fisheries and Aquaculture Report No 1001.

GFCM (2014). Report of the SCSA Working Group on Stock Assessment of Demersal Species (WGSAD). Bar, Montenegro.

Giannoulaki M., Iglesias M., Leonori I., Patti B., Pirounaki M.M., Tugores P., Campanella F., Siapatis A., Basilone G., D'Elia M., Machias A., De Felice A., Somarakis S., Valavanis V., Papadopoulou N., Nikolopoulou M., Bonanno A., Vasapollo C., Tsagarakis K. (2013). Mapping of nursery and spawning grounds of small pelagic fish. Mediterranean Sensitive Habitats (MEDISEH) Final Report, DG MARE Specific Contract SI2.600741, Heraklion.

Gili J.M., Coma R. (1998). Benthic suspension feeders: their paramount role in littoral marine food webs. *Trends in Ecology and Evolution* 13: 316-321.

Gilliers C., Amara R., Bergeron J.P., Le Pape O. (2004). Comparison of growth and condition indices of juvenile flatfish in different coastal nursery grounds. *Environmental Biology of Fishes* 71: 189-198.

Gislason H., Sinclair M. (2000). Ecosystem effects of fishing. *ICES Journal of Marine Science* 57: 465-791.

Gonzalez M., Barcala E., Perez-Gil J.L., Carrasco M.N., García-Martínez M.C. (2011) Fisheries and reproductive biology of *Octopus vulgaris* (Mollusca: Cephalopoda) in the Gulf of Alicante (Northwestern Mediterranean). *Mediterranean Marine Science* 12: 369-389.

Gonzalez M., Sanchez P. (2002). Cephalopod assemblages caught by trawling along the Iberian Peninsula Mediterranean coast. *Scientia Marina* 66: 199-208.

Goñi R., Latrouite D. (2005). Review of the biology, ecology and fisheries of *Palinurus* spp. Species of European waters: *Palinurus elephas* (Fabricius,

1787) and *Palinurus mauritanicus* (Gruvel, 1911). *Cahiers de Biologie Marine* 46: 127-142.

Grecay P.A., Targett T.E. (1996). Spatial patterns in condition and feeding of juvenile weakfish in Delaware Bay. *Transactions of the American Fisheries Society* 125: 803-808.

Guidetti P. (2000). Differences among fish assemblages associated with near shore *Posidonia oceanica* seagrass beds, rocky-algal reefs and unvegetated sand habitats in the Adriatic Sea. *Estuarine, Coastal and Shelf Science* 50: 515-529.

Guijarro B., Massutí E. (2006). Selectivity of diamond- and square-mesh codends in the deepwater crustacean trawl fishery off the Balearic Islands (western Mediterranean). *ICES Journal of Marine Science* 63: 52-67.

Guijarro B., Quetglas A., Moranta J., Ordines F., Valls M., González N., Massutí E. (2012). Inter- and intra-annual trends and status indicators of nektobenthic elasmobranchs off the Balearic Islands (northwestern Mediterranean). *Scientia Marina* 76: 87-96.

Harmelin J.G. (1987). Structure and variability of the ichthyofauna in a Mediterranean protected rocky area (National Park of Port-Cros, France). *Marine Ecology-Pubblicazioni Della Stazione Zoologica di Napoli I* 8: 263-284.

Harmelin-Vivien M.L., Harmelin J.G., Leboulleux V. (1995) Microhabitat requirements for settlement of juvenile sparid fishes on Mediterranean rocky shores. *Hydrobiologia* 300-301: 309-320.

Harmelin-Vivien M.L., Kaim-Malka R.A., Ledoyer M., Jacob-Abraham S.S. (1989). Food partitioning among Scorpaenid fishes in Mediterranean seagrass beds. *Journal of Fish Biology* 34: 715-734.

Hayes J., Shonkwiler J. (2001). Morphometric indicators of body condition: worthwhile or wish thinking?. In: Speakman J. (editor), Body composition analysis of animals: a handbook of non-destructive methods, pp. 8-38. Cambridge University Press, Cambridge,

Hidalgo M., Massutí E., Guijarro B., Moranta J., Ciannelli L.,Oliver P.,Stenseth N.C. (2009). Population effects and changes in life history traits in relation to phase transitions induced by long-term fishery harvesting: European hake (*Merluccius merluccius*) off the Balearic Islands. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 1355-1370.

Hiddink J.G., Jennings S., Kaiser M.J., Queirós A.M., Duplisea D.E., Piet G.J. (2006). Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 736: 721-736.

Hiddink J.G., Johnson A.F., Kingham R., Hinz H. (2011). Could our fisheries be more productive? Indirect negative effects of bottom trawl fisheries on fish condition. *Journal of Applied Ecology* 48: 1441-1449.

Hinojosa-Arango G., Riosmena-Rodriguez R. (2004). Influence of rodolith-forming species and growth-form on associated fauna of rodoliths beds in the central-west Gulf of California, México. *Marine Ecology-Pubblicazioni Della Stazione Zoologica di Napoli I* 25: 109-127.

Hinz H., Bergmann M., Shucksmith R., Kaiser M.J., Rogers S.I. (2006). Habitat association of plaice, sole, and lemon sole in the English Channel. *ICES Journal of Marine Science* 63: 912-927.

Hinz H., Prieto, V., Kaiser, M.J. (2009). Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecological Applications 19, 761-773.

Hogg M.M., Tendal O.S., Conway K.W., Pomponi S.A., van Soest R.W.M., Gutt J., Krautter M., Roberts J.M. (2010). Deep-sea Sponge Grounds: Reservoirs of Biodiversity. UNEP-WCMC Biodiversity Series No. 32. UNEP-WCMC, Cambridge.

Hureau J.C., Litvinenko N.I. (1986). Scorpaenidae. In: Whitehead P.J.P., Bauchot M.L., Hureau J.C., Nielsen J., Tortonese E. (editors), Fishes of the North-eastern Atlantic and the Mediterranean, pp. 1211-1229. UNESCO, Paris.

IEO (2012). Estrategia Marina. Demarcación Marina Levantino-Balear. Parte IV. Descriptores buen estado ambiental. Descriptor 1: Biodiversidad. Evaluación inicial y buen estado ambiental. Instituto Español de Oceanografía. http://www.magrama.gob.es/es/costas/temas/estrategias-marinas/IV_D1_Levantino-Balear_tcm7-207252.pdf. (Accessed 25/02/2014)

İlhan D., Akalin S., Tosunoğlu Z., Özaydin O. (2010). Growth characteristics and reproduction of comber, *Serranus cabrilla* (Actinopterygii, Perciformes, Serranidae), in the Aegean Sea. *Acta Ichthyologica et Piscatoria* 40: 55-60.

Isaksen B., Valdemarsen J.W., Larsen R.B., Karlsen L. (1992). Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. *Fisheries Research* 13: 335-352.

Ivory P., Jeal F., Nolan C.P. (2004). Age Determination, Growth and Reproduction in the Lesser-spotted Dogfish, *Scyliorhinus canicula* (L.). *Journal of Northwest Atlantic Fisheries Science* 35: 89–106.

Jackson D.A., Harvey H.H. (1992). Fish and benthic invertebrates: community concordance and community-environment relationships. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 2641-2651.

Jennings S. (2004). The ecosystem approach to fishery management: a significant step towards sustainable use of the marine environment?. *Marine Ecology Progress Series* 274: 279-282.

Jennings S., Dinmore T.A., Duplisea D.E., Warr K.J., Lancaster J.E. (2001). Trawling disturbance can modify benthic production processes. *Journal of Animal Ecology* 70: 45-475.

Jennings S., Kaiser M.J. (1998). The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34: 201-352.

Joher S., Ballesteros E., Cebrian E., Sánchez N., Rodríguez-Prieto C. (2012). Deep-water macroalgal-dominated coastal detritic assemblages on the continental shelf off Mallorca and Menorca (Balearic Islands, Western Mediterranean). *Botanica Marina* 55: 485-497.

Jokiel P.L. (1978). Effects of water motion on reef corals. *Journal of Experimental Marine Biology and Ecology* 35: 87-97.

Jones C.G., Lawton J.H., Shachak M. (1994). Organisms as ecosystem engineers. *Oikos* 69: 373-386.

Jones J.B. (1992). Environmental impact of trawling on the seabed?: a review. *New Zealand Journal of Marine and Freshwater Research* 26: 59-67.

Jones L.A., Hiscock K., Connor D.W. (2000). Marine habitat reviews. A summary of ecological requirements and sensitivity characteristics for the conservation and management of marine SACs. UK Marine SACs Project report. Joint Nature Conservation Committee, Peterborough.

Jordi A., Basterretxea G., Wang D.P. (2009). Evidence of sediment resuspension by island trapped waves. *Geophysical Research Letters* 36: L18610.

Juan-Jordá M.J., Barth J.A., Clarke M.E., Wakefield W.W. (2009). Groundfish species associations with distinct oceanographic habitats in the Northern California Current. *Fisheries Oceanography* 18: 1-19.

Kaiser M.J., Bergmann M., Hinz H., Galanidi M., Shucksmith R., Rees E.I.S., Darbyshire T., Ramsay K. (2004). Demersal fish and epifauna associated with sandbank habitats. *Estuarine, Coastal and Shelf Science* 60: 445-456.

Kaiser M., Clarke K., Hinz H., Austen M., Somerfield P., Karakassis I. (2006). Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series* 311: 1-14.

Kaiser M.J., de Groot S.J. (editors) (2000). The effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. Blackwell Science, Oxford.

Kaiser M.J., Rogers S.I., Ellis J.R. (1999). Importance of benthic habitat complexity for demersal fish assemblages. *American Fisheries Society Symposium* 22: 212-223.

Kallianiotis A., Sophronidis K., Virodis P., Tselepides A. (2000). Demersal fish and megafaunal assemblages on the Cretan continental shelf and slope

(NE Mediterranean): seasonal variation in species density, biomass and diversity. *Progress in Oceanography* 46: 429-455.

Kalogirou S., Corsini-Foka M., Sioulas A, Wennhage H., Pihl L. (2010). Diversity, structure and function of fish assemblages associated with *Posidonia oceanica* beds in an area of the eastern Mediterranean Sea and the role of non-indigenous species. *Journal of Fish Biology* 77: 2338-2357.

Kalogirou S., Wennhage H., Pihl L. (2012). Non-indigenous species in Mediterranean fish assemblages: Contrasting feeding guilds of *Posidonia oceanica* meadows and sandy habitats. *Estuarine, Coastal and Shelf Science* 96: 209-218.

Kamenos N.A., Moore P.G., Hall-Spencer J.M. (2004)a. Small-scale distribution of juvenile gadoids in shallow inshore waters; what role does maerl play?. *ICES Journal of Marine Science* 61: 422-429.

Kamenos N.A., Moore P.G., Hall-Spencer J.M. (2004)b. Nursery-area function of maërl grounds for juvenile queen scallops *Aequipecten opercularis* and other invertebrates. *Marine Ecology Progress Series* 274: 183-189.

Katsanevakis S., Maravelias C.D., Damalas D., Karageorgis A.P., Tsitsika E.V., Anagnostou C., Papaconstantinou C. (2009). Spatiotemporal distribution and habitat use of commercial demersal species in the eastern Mediterranean Sea. *Fisheries Oceanography* 18: 439-457.

Katsanevakis S., Verriopoulos G. (2004). Den ecology of *Octopus vulgaris* Cuvier, 1797, on soft sediment: availability and types of shelter. *Scientia Marina* 68: 147-157.

Kenchington E.L.R., Prena J., Gilkinson D.C., MacIsaac K., Bourbonnais C., Schwinghamer P.J., Rowell T.W., McKeown D.L., Vass W.P. (2001). Effects of experimental otter trawling on the macrofauna of a sandy bottom ecosystem on the Grand Banks of Newfoundland. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1043-1057.

Konstantinov K.G., Turuk T.N., Plekhanova N.A. (1985). Food links of some fishes and invertebrates on Flemish Cap. *NAFO Scientific Council Studies* 8: 39-48.

Krotoni V., Lagouvardos K., Lalas D. (2001). The effect of the island of Crete on the Etesian winds over the Aegean Sea. *Quarterly Journal of the Royal Meteorological Society* 127: 1917-1937.

La Mesa M., Arneri E., Caputo V., Iglesias M. (2005)a. The transparent Gob., *Aphia minuta*: review of biology and fisheries of a paedomorphic European fish. *Reviews in Fish Biology and Fisheries* 15: 89-109.

La Mesa M., La Mesa G., Micalizzi M. (2005)b. Age and growth of madeira scorpionfish, *Scorpaena maderensis* Valenciennes, 1833, in the central Mediterranean. *Fisheries Research* 74: 265-272.

Labropoulou M., Machias A. (1998). Effect of habitat selection on the dietary patterns of two triglid species. *Marine Ecology Progress Series* 173: 275-288.

Lambert Y., Dutil J.D. (1997). Can simple condition indices be used to monitor and quantify seasonal changes in the energy reserves of Atlantic cod (*Gadus morhua*)?. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 104-112.

Lambert Y., Dutil J.D. (2000). Energetic consequences of reproduction in Atlantic cod (*Gadus morhua*) in relation to spawning level of somatic energy reserves. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 815-825.

Lambert Y., Yaragina N.A., Kraus G., Marteinsdottir G., Wright P.J. (2003). Using environmental and biological indices as proxies for egg and larval production of marine fish. *Journal of Northwest Atlantic Fishery Science* 33: 115-159.

Levi F., Boutoute M., Mayzaud P. (2005). Lipid composition of *Symphodus ocellatus* (Perciformes: Labridae) in the north-western Mediterranean: influence of two different biotopes. *Marine Biology* 146: 805-814.

Levin P.S., Hay M.E. (1996). Responses of temperate reef fishes to alterations in algal structure and species composition. *Marine Ecology Progress Series* 134: 37-47.

Lleonart J., Maynou F. (2003). Fish stock assessments in the Mediterranean: state of the art. *Scientia Marina* 67: 37-49.

Lleonart J., Morales-Nin B., Massuti E., Deudero S., Reñones O. (1999). Population dynamics and fishery of dolphinfish (*Coryphaena hippurus*) in the western Mediterranean. *Scientia Marina* 63: 447-457.

Lleonart J., Salat J. (1992). VIT. Programa de análisis de pesquerías. *Informes Técnicos de Scientia Marina* 168-169, 116 pp.

Lloret J., de Sola L.G., Souplet A., Galzin R. (2002). Effects of large-scale habitat variability on condition of demersal exploited fish in the north-western Mediterranean. *ICES Journal of Marine Science* 59: 1215-1227.

Lloret J., Demestre M., Sánchez-Pardo J. (2007). Lipid reserves of red mullet (*Mullus barbatus*) during pre-spawning in the northwestern Mediterranean. *Scientia Marina* 71: 269-277.

Lloret J., Demestre M., Sánchez-Pardo J. (2008). Lipid (energy) reserves of European hake (*Merluccius merluccius*) in the north-western Mediterranean. *Vie et Milieu* 58: 75-85.

Lloret J., Galzin R., de Sola L.G., Souplet A., Demestre M. (2005). Habitat related differences in lipid reserves of some exploited fish species in the north-western Mediterranean continental shelf. *Journal of Fish Biology* 67: 51-65.

Lloret J., Planes S. (2003). Condition, feeding and reproductive potential of white seabream *Diplodus sargus* as indicators of habitat quality and the effect of reserve protection in the northwestern Mediterranean. *Marine Ecology Progress Series* 248: 197-208.

Lopez-Jurado J.L., Marcos M., Monserrat S. (2008). Hydrographic conditions affecting two fishing grounds of Mallorca island (Western Mediterranean): during the IDEA Project (2003-2004). *Journal of Marine Systems* 71: 303-315.

Lozano-Cabo F. (1953). Monografía de los centracántidos mediterráneos con un estudio especial de la biometría, biología y anatomía de *Spicara smaris* (L.). *Boletín del Instituto Español de Oceanografía* 59: 1-122.

Mace P.M. (2004). In defence of fisheries scientists, single-species models and other scapegoats: confronting the real problems. In: Browman H., Stergiou K.I. (Editors), Perspectives on ecosystem-based approaches to the management of marine resources. *Marine Ecology Progress Series* 274: 269-303.

MacLennan D.N. (editor) (1992). Fishing gear selectivity. *Fisheries Research* 13: 201-352.

Macpherson E. (1978). Food and feeding of *Micromesistius poutassou* (Risso, 1810) and *Gadiculus argenteus argenteus* Guichenot, 1950 (Pisces, Gadidae) in Mediterranean Sea. *Investigacion Pesquera* 42: 305-316.

Macpherson E. (1994). Substrate utilisation in a Mediterranean littoral fish community. *Marine Ecology Progress Series* 114: 211-218.

Madurell T., Cartes J.E., Labropoulou M. (2004). Changes in the structure of fish assemblages in a bathyal site of the Ionian Sea (eastern Mediterranean). *Fisheries Research* 66: 245-260.

Mallol S., Casadevall M., García E. (2001). Comparison of discarded, escaped and landed fish using diamond and square mesh codends. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 36: 296.

Mangano M., Kaiser M., Porporato E., Spanò N. (2013). Evidence of trawl disturbance on mega-epibenthic communities in the Southern Tyrrhenian Sea. *Marine Ecology Progress Series* 475: 101-117.

Manly B.F.J. (1991). Randomization and Monte Carlo methods in biology. Chapman and Hall, London.

Mann K., Lazier J. (1991). Dynamics of marine ecosystems: biological-physical interactions in the oceans. Blackwell, London.

Marrack E.C. (1999). The relationship between water motion and living rhodolith beds in southwestern Gulf of California, Mexico. *Palaios* 14: 159-171.

Marshall C.T., Frank K.T. (1999). The effect of interannual variation in growth and condition on haddock recruitment. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 347-355.

Marshall C.T., Yaragina N.A., Lambert Y., Kjesbu O. (1999). Total lipid energy as a proxy for total egg production by fish stocks. *Nature* 402: 288-290.

Martí R., Uriz M.J., Ballesteros E., Turon X. (2005). Seasonal variation in structure of three algal communities under different light conditions. *Estuarine Coastal and Shelf Science* 64: 613-622.

Massutí E., Monserrat S., Oliver P., Moranta J., López-Jurado J.L., Marcos M., Hidalgo M., Guijarro B., Carbonell A., Pereda P. (2008). The influence of oceanographic scenarios on the population dynamics of demersal resources in the western Mediterranean?: Hypothesis for hake and red shrimp off Balearic Islands. *Journal of Marine Systems* 71: 421-438.

Massutí E., Morales-Nin B., Moranta J. (2000). Age and growth of blue-mouth, *Helicolenus dactylopterus* (Osteichthyes: Scorpaenidae), in the western Mediterranean. *Fisheries Research* 46: 165-176.

Massutí E., Moranta J. (2003). Demersal assemblages and depth distribution of elasmobranches from the continental shelf and slope off the Balearic Islands (western Mediterranean). *ICES Journal of Marine Science* 60: 753-766.

Massutí E., Ordines F., Guijarro B. (2009). Efficiency of flexible sorting grids to improve size selectivity of the bottom trawl in the Balearic Islands (western Mediterranean), with comparison to a change in mesh cod-end geometry. *Journal of Applied Ichthyology* 25: 153-161.

Massutí E., Reñones O. (2005). Demersal resource assemblages in the trawl fishing grounds off the Balearic Islands (western Mediterranean). *Scientia Marina* 69: 167-181.

Maynou F., Cartes J.E. (2000). Community structure of bathyal decapod crustaceans off south-west Balearic Islands (western Mediterranean): seasonality and regional patterns in zonation. *Journal of the Marine Biological Association of the United Kingdom* 80: 789-798.

Mazzella L., Scipione M.B., Gambi M.C., Buia M.C., Lorenti M., Zupo V., Cancemi G. (1993). The Mediterranean seagrass *Posidonia oceanica* and *Cymodocea nodosa*. A comparative overview. In: Ozhan E. (Editor), The First Conference on the Mediterranean Coastal Environment, MEDCOAST 93, pp. 103-116. Antalya.

McConnaughey R.A., Mier K.L., Dew C.B. (2000). An examination of chronic trawling effects on soft-bottom benthos of the eastern Bering Sea. *ICES Journal of Marine Science* 57: 1377-1388.

McPherson L.R., Slotte A., Kvamme C., Meier S., Marshall C.T. (2011). Inconsistencies in measurement of fish condition: a comparison of four

indices of fat reserves for Atlantic herring (*Clupea harengus*). *ICES Journal of Marine Science* 68: 52-60.

Merayo C.R. (1996). Seasonal changes in the biochemical composition of the muscle and liver of bib (*Trisopterus luscus* L.) (Pisces, Gadidae) from the Cantabrian Sea (N Spain). *Scientia Marina* 60: 489-495.

Messieh S.N., Rowell T.W., Peer D.L., Cranford P.J. (1991). The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. *Continental Shelf Research* 11: 1237-1263.

Metin C., Tokac A., Ulas A., Düzbastılar F.O., Lök A., Özbilgin H., Metin G., Tosunoğlu Z., Kaykac H., Aydın C. (2004). Survival of red mullet (Mullus barbatus L., 1758) after escape from a trawl codend in the Aegean Sea. *Fisheries Research* 70: 49-53.

Millot C. (1999). Circulation in the Western Mediterranean sea. *Journal of Marine Systems* 20: 423-442.

Minello T. (1999). Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. In L.R. Benaka (editor) Essential Fish Habitat and Rehabilitation, pp. 43-75. American Fisheries Society, Bethesda, Maryland.

Morales-Nin B. (1987). Métodos de determinación de la edad de los osteíctios en base a estructuras de crecimiento. *Informes Técnicos de Investigación Pesquera* 143: 1-30.

Morales-Nin B. (1992). Determination of growth in bony fishes from otolith microstructure. *FAO Fisheries technical Paper* 322: 1-51.

Morales-Nin B., Moranta J., Garcia C., Tugores M.P., Grau A.M., Riera F., Cerdà M. (2005). The recreational fishery off Majorca Island (western Mediterranean): some implications for coastal resource management. *ICES Journal of Marine Science* 62: 727-739.

Moranta J., Massutí E., Morales-Nin B. (2000). Fish catch composition of the deep-sea decapod crustacean fisheries in the Balearic Islands (western Mediterranean). *Fisheries Research* 45: 253-264.

Moranta J., Palmer M., Morey G., Ruiz A., Morales-Nin B. (2006). Multi-scale spatial variability in fish assemblages associated with *Posidonia oceanica* meadows in the Western Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 68: 579-592.

Moranta J., Quetglas A., Massutí E., Guijarro B., Ordines F., Valls M. (2008). Research trends on demersal fisheries oceanography in the Mediterranean. In: Mertens L.P. (editor), Biological Oceanography Research Trends, pp. 9-65. Nova Science Publishers Inc., New York.

Moranta J., Stefanescu C., Massutí E., Morales-Nin B., Lloris D. (1998). Fish community structure and depth related trends on the continental slope of

the Balearic Islands (Algerian basin, western Mediterranean). *Marine Ecology Progress Series* 171: 247-259.

Morey G., Moranta J., Massuti E., Grau A., Linde M., Riera F., Morales-Nin B. (2003). Weight-length relationships of litoral to lower slope fishes from the western Mediterranean. *Fisheries Research* 62: 89-96.

Morgan M.J. (2004). The relationship between fish condition and the probability of being mature in American plaice (*Hippoglossoides platessoides*). *ICES Journal of Marine Science* 61: 64-70.

Morte S., Redón M.J., Sanz-Brau A. (2001). Diet of *Scorpaena porcus* and *Scorpaena notata* (Pisces: Scorpaenidae) in the Western Mediterranean. *Cahiers de Biologie Marine* 42: 333-344.

Muñoz M., Casadeval M. (2002). Reproductive indices and fecundity of *Helicolenus dactylopterus dactylopterus* (Teleostei: Scorpaenidae) in the Catalan Sea (western Mediterranean). *Journal of the Marine Biological Association of the United Kingdom* 82: 995-1000.

Muñoz M., Casadevall M., Bonet S. (2002)a. Testicular structure and semicystic spermatogenesis in a specialized ovuliparous species: *Scorpaena notata* (Pisces, Scorpaenidae). *Acta Zoologica* 83: 213-219.

Muñoz M., Casadevall M., Bonet S. (2002)b. The ovarian morphology of *Scorpaena notata* shows a specialized mode of oviparity. *Journal of Fish Biology* 61: 877-887.

Muñoz M., Sàbat M., Vila S., Casadevall M. (2005). Annual reproductive cycle and fecundity of *Scorpaena notata* (Teleostei: Scorpaenidae). *Scientia Marina* 69: 555-562.

Murray S.P., Roberts H.H., Conlon D.M., Rudder G.M. (1977). Nearshore current fields around coral islands: control on sediment accumulation and reef growth. In: Taylor D.L. (Editor), Proceedings, Third International Coral Reef Symposium Vol. 2: Geology, pp. 54-59. Rosenstiel School of Marine and Atmospheric Science, Miami.

Murzina S.A., Meyer Ottesen C.A., Falk-Petersen S., Hop H., Nemova N.N., Poluektova O.G. (2012). Oogenesis and lipids in gonad and liver of daubed shanny (*Leptoclinus maculatus*) females from Svalbard waters. *Fish Physiology and Biochemistry* 38: 1393-1407.

Myers R.A. Mertz G. (1998) The limits of exploitation: a precautionary approach. *Ecological Applications* 8: 165-169.

Naranjo S.A., Carballo J.L., Garcia-Gomez J.C. (1996). Effects of environmental stress on ascidian populations in Algeciras Bay (southern Spain). Possible marine bioindicators?. *Marine Ecology Progress Series* 144: 119-131.

Norkko A., Bonsdorff E. (1996)a. Rapid zoobenthic community responses to accumulations of drifting algae. *Marine Ecology Progress Series* 131: 143-157.

Norkko A., Bonsdorff E. (1996)b. Population responses of coastal zoobenthos to stress induced by drifting algal mats. *Marine Ecology Progress Series* 140: 141-151.

Norkko J., Bonsdorff E., Norkko A. (2000). Drifting algal mats as an alternative habitat for benthic invertebrates: Species specific responses to a transient resource. *Journal of Experimental Marine Biology and Ecology* 248: 79-104.

Norkko A., Thrush S.F., Cummings V.J., Funnell G.A., Schwarz A.M., Andrew N.L., Hawes I. (2004). Ecological role of *Phyllophora Antarctica* drift accumulations in coastal soft-sediment communities. *Polar Biology* 27:482-494.

Oliver P. (1993). Analysis of fluctuations observed in the trawl fleet landings of the Balearic Islands. *Scientia Marina* 57: 219-227.

Ordines F., Jordá G., Quetglas A., Flexas M., Moranta J., Massutí E. (2011). Connections between hydrodynamics, benthic landscape and associated fauna in the Balearic Islands, western Mediterranean. *Continental Shelf Research* 31: 1835-1844.

Ordines F., Massutí E. (2009). Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 370-383.

Ordines F., Massutí E., Guijarro B., Mas R. (2006). Diamond vs. square mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquatic Living Resources* 19: 329-338.

Ordines F., Massutí E., Quetglas A., Moranta J. (2007). Macro-epibenthic assemblages on the trawling grounds along the shallow continental shelf off the Balearic islands (western Mediterranean). *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 38: 561.

Ordines F., Quetglas A., Massutí E., Moranta J. (2009). Habitat preferences and life history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. *Estuarine, Coastal and Shelf Science* 85: 537-546.

Pajuelo J.G., Lorenzo J.M. (1998). Population biology of the common pandora *Pagellus erythrinus* (Pisces: Sparidae) off the Canary Islands. *Fisheries Research* 36: 75-86.

Pajuelo J.G., Lorenzo J.M. (2000). Reproduction, age, growth and mortality of axillary seabream, *Pagellus acarne* (Sparidae), from the Canarian archipelago. *Journal of Applied Ichthyology* 16: 41-47.

Pallares P. (1992). Comparación de los resultados de la aplicación de técnicas de análisis de población virtual sobre distribuciones de edad y distribuciones de tallas con aplicaciones a la evaluación de stocks explotados de diferentes grupos taxonómicos. Ph.D. Thesis, Universidad Complutense Madrid, 173 pp.

Palmer M., Quetglas A., Guijarro B., Moranta J., Ordines F., Massutí E. (2009). Performance of artificial neural networks and discriminant analysis in predicting fishing tactics from multispecific fisheries. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 224-237.

Pardoe H., Thordarson G., Marteinsdottir G. (2008). Spatial and temporal trends in condition of Atlantic cod *Gadus morhua* on the Icelandic shelf. *Marine Ecology-Progress Series* 362: 261-277.

Pauly D., Christensen V., Guénette S., Pitcher T.J., Sumalia U.R., Walters C.J., Watson R., Zeller D. (2002). Towards sustainability in world fisheries. *Nature* 418: 689-695.

Pérès J.M. (1967). The Mediterranean benthos. *Oceanography and Marine Biology: An Annual Review* 5: 449-533.

Pérès J.M. (1985). History of the Mediterranean biota and the colonization of the depths. In: Margalef R. (Editor), Western Mediterranean, pp. 198-232. Pergamon Press, London.

Pérès J.M., Picard J. (1964). Nouveau Manuel de bionomie benthique de la mer Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume* 31: 1-137.

Peres-Neto P.R., Legendre P., Dray S., Borcard D. (2006). Variation partitioning of species data matrices: estimation and comparison of fractions. *Ecology* 87: 2614-2625.

Petersen C.G.J. (1915). On the animal communities of the sea bottom in the Skagerak, the Christiania Fjord and the Danish waters. *Report of the Danish Biological Station* 23: 1-28.

Petrakis G., Stergiou K.I. (1997). Size selectivity of diamond and square mesh codends for four commercial Mediterranean fish species. *ICES Journal of Marine Science* 54: 13-23.

Pichon M. (1977). Physiography, morphology and ecology of the Double Barrier reef of North Bohol (Philippines). In: Taylor D.L. (Editor), Proceedings, Third International Coral Reef Symposium Vol. 2: Geology, pp. 261-267. Rosenstiel School of Marine and Atmospheric Science, Miami.

Pickitch E.K., Santora C., Babcock E.A., Bakun A., Bonfil R., Conover D.O., Dayton P., Doukakis P., Fluharty D., Heneman B., Houde E.D., Link J., Livingston P.A., Mangel M., McAllister M.K., Pope J., Sainsbury K.J. (2004). Ecosystem-based fishery management. *Science* 305: 346-347.

Pinot J.M., López-Jurado J.L., Riera M. (2002). The CANALES experiment (1996-1998). Interannual, seasonal, and mesoscale variability of the circulation in the Balearic Channels. *Progress in Oceanography* 55: 335-370.

Pinot J.M., Tintore J., Gomis D. (1994). Quasi-synoptic mesoscale variability in the Balearic Sea. *Deep-Sea Research Part I-Oceanographic Research Papers* 41: 897-914.

Pinot J.M., Tintoré J., Gomis D. (1995). Multivariate analysis of the surface circulation in the Balearic Sea. *Progress in Oceanography* 36: 343-376.

Pitcher C.R., Poiner I.R., Hill B.J., Burridge C.Y. (2000). Implications of the effects of trawling on sessile megazoobenthos on a tropical shelf in northeastern Australia. *ICES Journal of Marine Science* 57: 1359-1368.

Pothoven S.A, Nalepa T.F., Madenjian C.P., Rediske R.R., Schneeberger P.J., He J.X. (2006). Energy density of lake whitefish *Coregonus clupeaformis* in Lakes Huron and Michigan. *Environmental Biology of Fishes* 76: 151-158.

Puig P., Canals M., Company J.B., Martín J., Amblas D., Lastras G., Palanques A., Calafat A.M. (2012). Ploughing the deep sea floor. *Nature* 489: 286-289.

Quetglas A., Alemany F., Carbonell A., Merella P., Sánchez P. (1998). Biology and fishery of Octopus vulgaris Cuvier, 1797, caught by trawlers in Mallorca (Balearic Sea, Western Mediterranean. Fisheries Research 36: 237-249.

Quetglas A., Guijarro B., Ordines F., Massutí E. (2012). Stock boundaries for fisheries assessment and management in the Mediterranean: the Balearic Islands as a case study. *Scientia Marina* 76: 17-28.

Quetglas A., Ordines F., Hidalgo M., Monserrat S., Ruiz S., Amores A., Moranta J., Massutí E. (2013). Synchronous combined effects of fishing and climate within a demersal community. *ICES Journal of Marine Science* 70: 319-328.

Ragonese S., Zagra M., Di Stefano L., Bianchini M.L. (2001). Effect of codend mesh size on the performance of the deep-water bottom trawl used in the red shrimp fishery in the Strait of Sicily (Mediterranean Sea). *Hydrobiologia* 449: 279-291.

Rätz H.J., Lloret J. (2003). Variation in fish condition between Atlantic cod (*Gadus morhua*) stocks, the effect on their productivity and management implications. *Fisheries Research* 60: 369-380.

Raventos N., Macpherson E. (2005). Environmental influences on temporal patterns of settlement in two littoral labrid fishes in the Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 63: 479-487.

Redón M.J., Morte M.S., Sanzbrau A. (1994). Feeding habits of the spotted flounder *Citharus linguatula* off the eastern coast of Spain. *Marine Biology* 120: 197-201.

Renous S., Gasc J.P., Bels V.L., Davenport J. (2000). Six-legged walking by a bottom-dwelling fish. *Journal of the Marine Biological Association of the United Kingdom* 80: 757-758.

Reñones O., Massutí E., Morales-Nin B. (1995). Life history of red mullet (*Mullus surmuletus*) from the bottom trawl fishery off Mallorca Island (NW Mediterranean). *Marine Biology* 123: 411-419.

Rideout R.M., Rose G.A. (2006). Suppression of reproduction in Atlantic cod *Gadus morhua*. *Marine Ecology Progress Series* 320: 267-277.

Roberts C. M. (2002). Deep impact?: the rising toll of fishing in the deep sea. *Trends in Ecology and Evolution* 17: 242-245.

Roberts C.M., Bohnsack J.A., Gell F., Hawkins J.P., Goodridge R. (2001). Effects of marine reserves on adjacent fisheries. *Science* 294 (5548): 1920-1923.

Robertson J.H.B., Stewart P.A.M. (1988), A comparison of size selection of haddock and whiting by square and diamond mesh codends. *ICES Journal of Marine Science* 44: 148-161.

Rosenberg A., Bigford T.E., Leathery S., Hill R.H., Bickers K. (2000). Ecosystem approaches to fishery management through essential fish habitat. *Bulletin of Marine Science* 66: 535-542.

Rozas L.P., Odum W.E. (1988). Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. *Oecologia* 77: 101-106.

Sainsbury K.J., Campbell R.A., Lindholm R., Whitelaw A.W. (1997). Experimental management of an Australian multispecies trawl fishery: examining the possibility of trawl induced habitat modification. pp 107-112. In: Pickitch E.L., Huppert D.D., Sissenwine M.P. (editors), Global Trends: Fisheries Management. American Fisheries Society Symposium 20, Bethesda, Maryland.

Sainsbury K.J., Punt A.E., Smith A.D.M. (2000). Design of operational management strategies for achieving fishery ecosystem objectives. *ICES Journal of Marine Science* 57: 731-741.

Sampedro P., Saínza M., Trujillo V. (2005). A simple tool to calculate biological parameter's uncertainty. Working Document in Workshop on Sampling Design for Fisheries Data. ICES CM 2005/ACFM:11, Pasajes.

Sánchez P., Demestre M., Martin P. (2004). Characterisation of the discards generated by bottom trawling in the northwestern Mediterranean. *Fisheries Research* 67: 71-80.

Sánchez P., Demestre M., Ramon M., Kaiser M.J. (2000). The impact of otter trawling on mud communities in the northwestern Mediterranean. *ICES Journal of Marine Science* 57: 1-7.

Sangster G.I., Lehmann K., Breen M. (1996). Commercial fishing experiments to asses the survival of haddock and whiting after escape from four sizes of diamond mesh cod-ends. *Fisheries Research* 25: 323-345.

Sanz A. (1985). Contribution to the study of the biology of *Uranoscopus scaber* Linnaeus, 1758 (Osteichthyes, Uranoscopidae) of the western Mediterranean. *Investigacion Pesquera* 49: 35-46.

Sardà F., Bahamon N., Molí B., Sardà-Palomera F. (2006). The use of a square mesh codend and sorting grids to reduce catches of young fish and improve sustainability in a multispecies bottom trawl fishery in the Mediterranean. *Scientia Marina* 70: 347-353.

Sardà F., Bahamon N., Sardà-Palomera F., Molí B. (2005). Commercial testing of a sorting grid to reduce catches of juvenile hake (*Merluccius merluccius*) in the western Mediterranean demersal trawl fishery. *Aquatic Living Resources* 18: 87-91.

Sardà F., Lleonart J. (1993). Evaluation of the Norway lobster (*Nephrops norvegicus*, L.) resource off the "Serola" bank off Barcelona (western Mediterranean). *Scientia Marina* 57: 191-197

Schunter C., Carreras-Carbonell J., Macpherson E., Tintoré J., Vidal-Vijande E., Pascual A., Guidetti P., Pascual M. (2011). Matching genetics with oceanography: directional gene flow in a Mediterranean fish species. *Molecular Ecology* 20: 5167-5181.

Sciberras M., Rizzo M., Mifsud J.R., Camilleri K., Borg J.A., Lanfranco E., Schembri P.J. (2009). Habitat structure and biological characteristics of a maerl bed off the northeastern coast of the Maltese Islands (central Mediterranean). *Marine Biodiversity* 39: 251-264.

Shulman G.E., Love R.M. (1999). The Biochemical Ecology of Marine Fishes. In: Southward A.J., Tayler P.A., Young C.M. (editors), Advances in Marine biology vol. 36. Academic Press, London.

Skjæraasen J.E., Nash R.D.M., Korsbrekke K., Fonn M., Nilsen T., Kennedy J., Nedreass K.H., Thorsen A., Witthamnes P.R., Geffen A.J., Høie H., Kjesbu O.S. (2012). Frequent skipped spawning in the world's largest cod population. *Proceedings of the National Academy of Sciences* 109: 8995-8999.

Smith C.J., Papadopoulou K.N., Diliberto S. (2000). Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. *ICES Journal of Marine Science* 57: 1340-1351.

Somarakis S., Stamataki C., Machias A., Papadopoulou N., Smith C., Karakassis I. (2004). Condition and fecundity of red mullet over muddy and "coralligene" substrata. *Rapport de la Commision Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 37: 443.

Soto J. (1990). Vegetación algal sobre sustrato móvil de la zona circalitoral del Sureste de la Península Ibérica: una aproximación. *Folia Botanica Miscelania* 7: 43-49.

STECF (2006). Scientific, Technical and Economic Committee for Fisheries opinion on 'sensitive and essential fish habitats in the Mediterranean Sea' Commiission staff working paper, Rome, 48 pp.

Steller D.L., Riosmena-Rodriguez R., Foster M.S., Roberts C.A. (2003). Rhodolith bed diversity in the Gulf of California: the importance of rhodolith structure and consequences of disturbance. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12: S5-S20.

Stergiou K.I., Politou C.Y., Christou E.D., Petrakis G. (1997). Selectivity experiments in the NE Mediterranean: the effect of trawl codend mesh size on species diversity and discards. *ICES Journal of Marine Science* 54: 774-786.

Stevens J.D., Bonfil R., Dulvy N.K., Walker P.A. (2000). The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science* 57: 476-494.

Suuronen P., Jounela P., Tschernij V. (2010). Fishermen responses on marine protected areas in the Baltic cod fishery. *Marine Policy* 34: 237-243.

Tenore K.R., Zajac R.N., Terwin J., Andrade F., Blanton J., Boynton W., Carey D., Diaz R., Holland A.F., Lopez-Jamar E., Montagna P., Nichols F., Rosenberg R., Queiroga H., Sprung M., Whitlatch R.B. (2006). Characterizing the role benthos plays in large coastal seas and estuaries: a modular approach. *Journal of Experimental Marine Biology and Ecology* 330: 392-402.

ter Braak C.J.F., Smilauer P. (2002). CANOCO reference manual and user's guide to Canoco for windows: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca, New York.

Terrats A., Petrakis G., Papaconstantinou C. (2000). Feeding habits of *Aspitrigla cuculus* (L., 1758) (red gurnard), *Lepidotrigla cavillone* (Lac., 1802) (large scale gurnard) and *Trigloporus lastoviza* (Brunn.,1768) (rock gurnard) (E. Mediterranean) around Cyclades and Dodecanese Islands. *Mediterranean Marine Science* 1: 91-104.

Thistle D., Yingst J.Y., Fauchald K. (1985). A deep-sea benthic community exposed to strong near-bottom currents on the Scotian Rise (western Atlantic). *Marine Geology* 66: 91-112.

Tokai T. (1997). Maximum likelihood parameter estimates of a mesh selectivity logistic model through SOLVER on MS-Excel. *Bulletin of the Japanese Society of Fisheries Oceanography* 61: 288-298.

Torcu-Koc H., Türker-Cakir D., Dulčić J. (2004). Age, growth and mortality of the comber, *Serranus cabrilla* (Serranidae) in the Edremit Bay (NW Aegean Sea, Turkey). *Cybium* 28: 19-25.

Underwood A.J. (1981). Techniques of analysis of variance in experimental marine biology and ecology. *Oceanography and Marine Biology: An Annual Review* 19: 513-605.

Uranga I. (2012). Ciclo vital, ecología y pesquería de dos especies simpátricas de calamar en el Mediterráneo Occidental. MSc. Thesis, Universitat de les Illes Balears. 53 pp.

Vasilakopoulos P., Maravelias C.D., Tserpes G. (2014). The alarming decline of Mediterranean fish stocks. *Current Biology* 24: 1-6.

Vassilopoulou V., Papaconstantinou C. (1994). Age, growth and mortality of the spotted flounder (*Citharus linguatula* Linnaeus, 1758) in the Aegean Sea. *Scientia Marina* 58: 261-267.

Vetter E.W. (1995). Detritus-based patches of high secondary production in the nearshore benthos. *Marine Ecology Progress Series* 120: 251-262.

Vetter E.W., Dayton P.K. (1998). Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system. *Deep-Sea Research Part II: Topical Studies in Oceanography* 45: 25-54.

Vetter E.W., Dayton P.K. (1999). Organic enrichment by macrophyte detritus, and abundance patterns of megafaunal populations in submarine canyons. *Marine ecology Progress Series* 186: 137-148.

Vogel S. (1994). Life in moving fluids. Princeton University Press, Princeton, New Jersey.

Warwick R.M. (1984). The benthic ecology of the Bristol Channel. *Marine Pollution Bulletin* 15: 70-76.

Warwick R.M., Uncles R.J. (1980). Distribution of benthic macrofauna associations in the Bristol Channel in relation to tidal stress. *Marine Ecology Progress Series* 3: 97-103.

Watling L., Norse E.A. (1998). Disturbance of the Seabed by Mobile Fishing Gear: A Comparison to Forest Clearcutting. *Conservation Biology* 12: 1180-1197.

Werner F.E., Viúdez A., Tintoré J. (1993). An exploratory numerical study of the currents off the southern coast of Mallorca including the Cabrera island complex. *Journal of Marine Systems* 4: 45-66.

Wileman D.A., Ferro R.S.T., Fonteyne R., Millar R.B. (editors) (1996). Manual of methods of measuring the selectivity of towed fishing gears. *ICES Cooperative Research Report,* 215.

Wilson S., Blake C., Berges J.A., Maggs C.A. (2004). Environmental tolerances of free-living coralline algae (maerl): implications for European marine conservation. *Biological Conservation* 120: 279-289.

Wodinsky J. (1972). Breeding season of *Octopus vulgaris*. *Marine Biology* 16: 59-63.

Yaragina N.A., Marshall C.T. (2000). Trophic influences on interannual and seasonal variation in the liver condition index of Northeast Arctic cod (*Gadus morhua*). *ICES Journal of Marine Science* 57: 42-55.

Zaitsev Y.P. (1992). Recent changes in the trophic structure of the Black Sea. *Fisheries Oceanography* 1: 180-190.

Zimmermann M. (2006). Benthic fish and invertebrate assemblages within the National Marine Fisheries Service US west coast triennial bottom trawl survey. *Continental Shelf Research* 26: 1005-1027.

ANNEX

(Translation to catalan of the Introduction)

Introducció

Les primeres queixes sobre l'impacte de la pesca de ròssec es remunten al segle XIV. L'any 1376 els pescadors britànics que utilitzaven altres ormejos elevaren al Parlament les seves preocupacions sobre el mal que feia la pesca de ròssec de fons a les seves pesqueres. Estaven convençuts que destruïa la fauna i flora del fons, i feia malbé el peix petit i les espècies que no eren objectiu comercial (Messieh et al., 1991; Jones, 1992). Aquestes mateixes preocupacions es repeteixen al segle XVII i XVIII a la Mediterrània occidental, tal i com recull l'obra *Observaciones sobre la pesca llamada de parejas de bou: Utilidad y necesidad de su uso en el Golfo de Valencia*, de l'any 1866. Aquest document relata els conflictes de competència entre pescadors de diversos ormejos i els dedicats a la pesca de ròssec al Golf de València. A més, s'hi recullen els arguments contra la pràctica de la pesca de ròssec enumerats a altres obres precedents com la de Duhamel du Monceau, *Traité Génèral des Pesches*, de l'any 1769, en la qual es qualifica la pesca de ròssec com a molt perjudicial perquè empra xarxes de grans dimensions i malles petites, amb molts de ploms, que quan es remolquen pel fons l' "aixequen i el trastornen", n' "arrabassen les herbes" i no permeten que cap peix escapi. Així, en els "paratges" en què es practica aquest tipus de pesquera, s'hi observa escassetat de peix. A l'obra abans esmentada també s'hi exposen arguments per tal d'intentar rebatre els anteriors, entre els quals destaquen: el benefici econòmic que suposava la pesca de ròssec, l'augment de l'abastiment de peix i la percepció, després d'un segle d'haver introduït aquesta activitat pesquera, que com més barques de bou hi havia, més abundància de peix hi havia a les platges de pesca tant per les barques de bou com per als pescadors que empraven altres ormejos.

Avui en dia, existeix un volum important d'informació científica que conclou que la pesca de ròssec (a partir d'ara ens centrarem en la que es fa emprant com a art de pesca un bou de fons i no altres ormejos arrossegats pel fons, per exemple el gànguil) té un impacte negatiu considerable sobre els ecosistemes marins. Els arts de ròssec (Figura I) graten i llauren el fons, resuspenen el sediment, extreuen i destrueixen físicament la flora i fauna del bentos (Jones, 1992) i donen lloc a una reducció de la producció, de la biomassa i de la biodiversitat dels fons explotats, així com a canvis en l'estructura de les seves comunitats bentòniques (Engel i Kvitek, 1998; Smith et al., 2000; Hiddink et al., 2006; Hinz et al., 2009).

La pesca de ròssec disminueix l'abundància dels organismes que amb el seu creixement i/o acció són capaços de crear hàbitats. Aquestes espècies anomenades *habitat engineers*, que podríem traduir com *constructors d'hàbitat*, són organismes majoritàriament sèssils i amb un desenvolupament vertical important, encara que també s'hi inclouen organismes capaços de modificar el substrat (Jones et al., 1994). La seva pèrdua fa que les comunitats bentòniques passin a estar dominades per organismes de la infauna amb un creixement més ràpid i a tenir una estructura tridimensional més senzilla i menys productiva (Jennings i Kaiser, 1998; Kaiser et al., 2000; Jennings et al., 2001; Coleman i Williams, 2002; Kaiser et al., 2006; Engel i Kvitek, 1998; Mangano et al., 2013). Els organismes del mega-zoobentos més vulnerables a l'impacte de la pesca de ròssec, aquells amb menys resiliència i una velocitat de

recuperació més lenta com per exemple els coralls, són els que primer veuen disminuïda la seva abundància o fins i tot desapareixen dels fons explotats (Pitcher et al., 2000; Fossa et al., 2002; Roberts, 2002). El mateix passa amb les espècies de la flora més vulnerables i de creixement més lent com són les algues coral·linàcies de vida lliure que formen els fons de maërl (Bordehore et al., 2003), coneguts com magrana.

Aquests *constructors d'hàbitat* marins no arriben a donar als fons marins la complexitat estructural generada pels seus homòlegs terrestres, com seria la vegetació que forma els boscos. No obstant, aquesta complexitat no deixa d'esser igualment important per a la conservació de la biodiversitat, fet que ha dut a comparar els efectes de la pesca de ròssec amb els de la tala forestal (Watling i Norse, 1998).

En qualsevol cas, no només són les espècies bentòniques les que reben l'impacte directe de la pesca de ròssec. La baixa selectivitat d'aquesta modalitat de pesca fa que els danys col·laterals s'estenguin també a espècies necto-bentòniques, en siguin o no l'objectiu comercial de la pesquera. Així, el rebuig d'espècies sense interès comercial, entre les quals hi poden haver taurons, rajades i altres espècies vulnerables, o bé individus d'espècies comercials que no arriben a la mida mínima legal per a poder ser comercialitzades, pot representar una proporció elevada de la captura. Això es dóna més freqüentment a llocs en què sumat a l'abundància d'individus immadurs s'hi afegeix la presència d'un nombre elevat d'espècies, com és el cas de la pesquera de ròssec de la Mediterrània (Moranta et al., 2008; Stergiou et al., 1997; Sánchez et al., 2004; entre d'altres).

Juntament amb la captura no desitjada, existeixen altres impactes tal vegada més difícils de quantificar. És el cas de la mortalitat dels individus que aconsegueixen escapar de les xarxes de ròssec, que depèn tant de les característiques de les espècies com dels ormejos i que pot oscil·lar entre el zero i el cent per cent,en el cas de les espècies més vulnerables (Broadhurst et al., 2006). Els únics estudis sobre la supervivència d'aquests individus que escapen de la xarxa a la Mediterrània s'han dut a terme a Turquia i han estimat taxes de supervivència entre 50 i 100% per alguns peixos de la plataforma costanera (Metin et al., 2004; Düzbastılar et al., 2010a, 2010b).

A més, moltes espècies necto-bentòniques (incloses aquelles que són l'objectiu de la pesca) depenen directament o indirecta de la producció de les comunitats bentòniques donat que s'alimenten d'invertebrats bentònics o bé d'altres preses que troben en aquesta producció la seva font d'aliment (Konstantinov et al., 1985; Messieh et al., 1991). Per tant, no és estrany que la disminució de la productivitat de les comunitats bentòniques afectades per la pesca de ròssec acabi també provocant una disminució de l'aliment disponible per a les espècies necto-bentòniques, que finalment veuen afectada de forma negativa la seva condició fisiològica (Hiddink et al., 2011). Entre els efectes més importants que té una davallada de la condició dels individus en una població, cal destacar els que afecten fases clau del seu cicle vital com són la supressió de la reproducció, el retard en la maduresa sexual, la baixa fecunditat, la disminució de les taxes de supervivència de larves i juvenils i, en general, un increment de la mortalitat natural (Marshall et al., 1999; Lambert

and Dutil, 2000; Morgan, 2004; Rideout and Rose, 2006; Skjæraasen et al., 2012). Tot això provoca una davallada de la productivitat de les poblacions i un augment de la seva vulnerabilitat als impactes antropogènics, entre els quals destaca la pesca (Dutil i Lambert, 2000; Hiddink et al., 2011).

Un altre impacte negatiu de la pesca de ròssec és la pèrdua de complexitat estructural dels hàbitats i la disminució de la rugositat i l'abundància de forats i escletxes, que són emprats per espècies necto-bentòniques petites i/o estadis juvenils com a recer front als predadors. Als fons uniformes, aquestes espècies estan més exposades, presenten mortalitats més elevades i poden ser menys abundants (Choat i Ayling, 1987; Carr, 1989; Connell i Jones, 1991; Edgar i Shaw, 1995; Levin i Hay, 1996).

Tot i que l'exposat fins ara ofereix una visió bastant negativa de la pesca de ròssec, no és menys cert que aquesta modalitat de pesca proporciona més del 50% de les captures desembarcades a nivell mundial (Broadhurst et al., 2006), que oscil·len al voltant de 80 milions de tones ajuntant totes les modalitats de pesca (FAO: http://www.fao.org/fishery/statistics). Per tant, no pareix realista pensar que a curt o mig termini, el ròssec pugui esser substituït a nivell global per altres tipus d'arts de pesca, capaços de seguir abastint d'aliments provinents de la mar en quantitats que satisfacin la demanda actual i així reduir d'una forma significativa l'impacte negatiu del ròssec. Amb tot, hi ha l'opció d'intentar optimitzar aquesta modalitat de pesca millorant-ne la seva selectivitat i reduint el seu impacte sobre les comunitats del fons, les espècies vulnerables i no comercialitzables, i els individus immadurs. Es tracta, en definitiva, d'intentar compatibilitzar la sostenibilitat de la pesquera de ròssec amb la conservació dels ecosistemes i els recursos marins vius.

En aquest sentit, l'augment de la mida i/o modificació de la geometria de la malla en el cop de les xarxes de ròssec són mesures que han donat bon resultat a l'hora de fer més selectiva aquesta pesquera i disminuir el rebuig i la captura d'individus per davall de la talla de primera maduresa i/o talla mínima legal en què es pot comercialitzar (p. ex. Sardà et al., 1993; Petrakis i Stergiou, 1997; Ragonese et al., 2001; Bahamón et al., 2006; Guijarro i Massutí, 2006). La col·locació de graelles separadores en les xarxes de ròssec també poden contribuir a assolir aquest objectiu (p.ex. Isaksen et al., 1992; Sardà et al., 2005, 2006; Massutí et al., 2009).

No obstant, cap d'aquestes mesures és capaç de reduir l'impacte negatiu del ròssec sobre les comunitats bentòniques. Gran part de l'impacte físic dels arts emprats no el fa la malla del cop, sinó el fet d'arrossegar pel fons els diferents elements que conformen l'art de ròssec, des de les portes metàl·liques fins la xarxa i les cadenes que porta a la plomada, passant per les malletes i els vents (Figura I).

La magnitud dels danys causats pels arts de ròssec sobre les comunitats bentòniques depèn en gran part de les característiques biològiques i de la capacitat de recuperació dels organismes que la integren. A la majoria de treballs dedicats a estudiar els efectes del ròssec sobre hàbitats biogènics, sobretot els formats principalment per organismes de creixement lent i més vulnerables com són els fons de maërl, els coralls d'aigües profundes o els fons

d'esponges, s'arriba a la conclusió que aquesta activitat pesquera causa danys severs, de recuperació a molt llarg termini o, fins i tot,irreversibles (p.ex. Fossa et al., 2002; Barbera et al., 2003; Kaiser et al., 2006; Hogg et al., 2010). Per altra banda, en la majoria de treballs, sobretot experimentals, s'arriba a la conclusió que l'impacte del ròssec és relativament baix i, fins i tot, efímer sobre fons sedimentaris de sorra i/o fang (p.ex. Sánchez et al., 2000; Kenchington et al., 2001; De Biasi, 2004; Kaiser et al., 2006). Tot i així, altres treballs duts a terme en condicions comercials, conclouen que l'impacte sobre aquests tipus de fons és acumulatiu i que pot donar lloc a canvis profunds de les comunitats bentòniques (Smith et al., 2000, Hinz et al., 2009) i, fins i tot, modificar el relleu del fons marí (Puig et al., 2012).

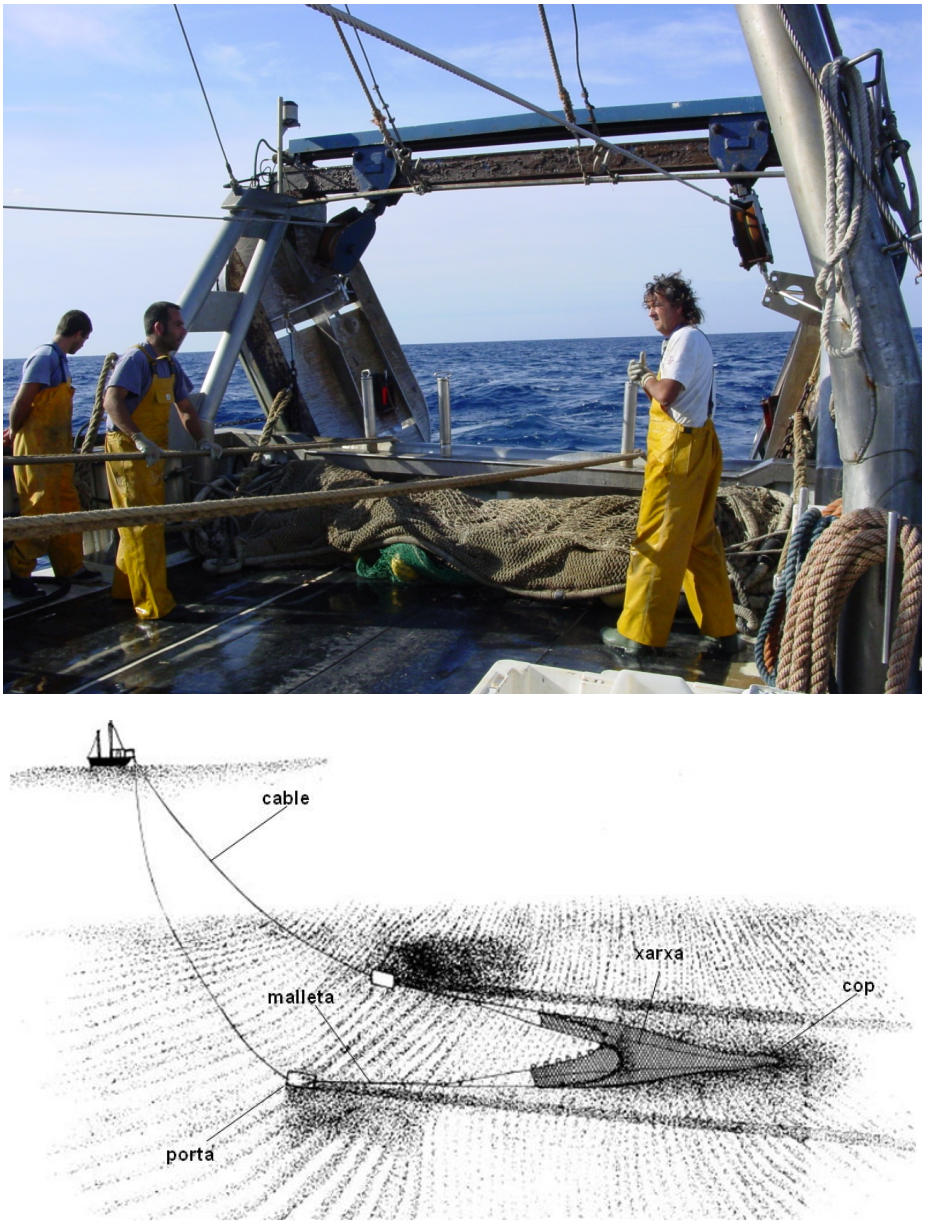


Figura I. Fotografia superior: maniobra de virada a bord d'una barca de bou de les Illes Balears, on es veu un bou no utilitzat plegat a la popa, la porta d'estribord (penjada a la banda d'estribord de popa), i les malletes (centre). Dibuix inferior: esquema d'una barca de bou pescant. Adaptat de www.gulfofmaine-census.org. Autor: Joseph DeAlteris.

Des de fa unes dècades, s'ha donat un canvi en com abordar l'avaluació i la gestió de les pesqueres, que ara tenen en compte no només les espècies objectiu sinó la totalitat de l'ecosistema i fins i tot els aspectes econòmics, socials i culturals de la pesca (Garcia et al., 2003; Pickitch et al., 2004; Browman i Stergiou, 2004; Coll et al., 2013). Aquesta nova manera d'abordar l'avaluació i la gestió de les pesqueres es coneix com a *Ecosystem Approach to Fisheries* (EAF), en contraposició a l'enfocament "tradicional" majoritàriament mono-específic, basat en l'estat de les poblacions dels recursos explotats. Per aplicar aquesta avaluació i gestió de pesqueres, ja incorporada a la Política Pesquera Comú de la Unió Europea, es necessiten coneixements detallats de com es relacionen els recursos explotats i els hàbitats on es desenvolupen i distribueixen, així com dels efectes de la pesca sobre aquests recursos i hàbitats i la resta de components de l'ecosistema. També es necessita saber quina n'és la seva vulnerabilitat i la seva capacitat de recuperació.

Tenint en compte l'elevat impacte de la pesca de ròssec sobre els ecosistemes i les espècies que exploten, l'aplicació de l'EAF ha d'esser prioritària, per tal de permetre, entre d'altres objectius 1) disminuir l'impacte sobre els hàbitats bentònics; 2) garantir la sostenibilitat de les poblacions de les espècies objectiu de la pesca amb la disminució de la captura d'individus per davall de la seva talla de primera maduresa; i 3) disminuir la captura d'espècies vulnerables i d'aquelles sense valor comercial.

Mantenir els hàbitats en bon estat és essencial perquè les espècies que els habiten puguin deenvolupar el seu cicle vital. Des del punt de vista de l' EAF, s'han definit els *Sensitive habitats* i els *Essential Fish Habitats*. Pel que fa referència al Mediterrani, el *Scientific, Technical and Economic Commitee for Fisheries* (STECF), de la Comissió Europea, va adoptar les següents definicions (STECF, 2006):

Sensitive Habitats: Hàbitats fràgils, reconeguts internacionalment com a importants des del punt de vista ecològic, que mantenen poblacions importants d'espècies de peixos comercials i no comercials, i que requereixen d'una protecció especial (p.ex. praderies de Posidònia).

Essential Fish Habitats: Hàbitats identificats com essencials pels requeriments ecològics i biològics de fases crítiques del cicle vital de les espècies de peixos explotades, i que poden requerir una protecció especial per a poder millorar l'estat d'aquestes poblacions i la seva sostenibilitat a llarg a termini.

La pesquera de ròssec de les Illes Balears

El Mediterrani és un mar caracteritzat per una gran diversitat d'espècies i biocenosis (Pérès i Picard, 1964; Fredj et al., 1992; Bianchi i Morri, 2000). Tot i només representar el 0.7% de la superfície marina global, aporta una producció pesquera que oscil·la al voltant de les 900000 tones anuals (Figura II) que representa més de l'1% de la producció pesquera mundial.

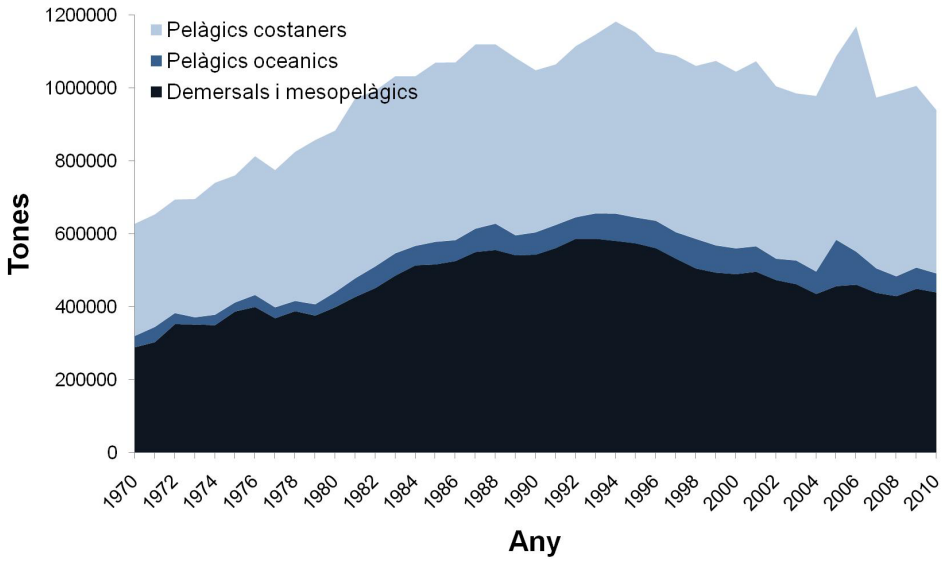


Figura II. Evolució temporal dels desembarcaments pesquers al Mediterrani. Font: FAO FishStat versió 2.0.0.

La major part de les captures de les pesqueres del Mediterrani són peixos pelàgics costaners, principalment sardina (*Sardina pilchardus*) i aladroc (*Engraulis encrasicholus*), que representen entre el 55 i el 60% dels desembarcaments (Figura II). Les captures de recursos demersals representen el 40-45% del total i a diferència de les anteriors, destaquen pel seu caràcter multi-específic, amb un gran nombre d'espècies tant de peixos com d'invertebrats, que s'obtenen mitjançant una gran varietat d'arts i ormejos de pesca, entre els quals destaca la pesquera que es realitza amb xarxes de ròssec de fons, tant per la potència i capacitat de pesca de la flota que els empra, com per les seves captures (Lleonart i Maynou, 2003).

Les Illes Balears no són una excepció, tant pel que fa al caràcter multi-espec'ific de les captures de recursos demersals com per la importància de la pesquera de ròssec, coneguda com a pesca de bou, en aquests desembarcaments. Tal vegada en poden esser un clar exemple d'ambdós, no exempt de certes característiques que les distingeixen fins i tot de les costes continentals més properes de la Mediterrània occidental.

A les Illes Balears la pesca de bou té una gran importància relativa si es compara amb altres zones. Mentre que a les costes veïnes del nord-est de la Península Ibèrica la pesca de bou representa prop del 45-50% dels

desembarcaments i l'altre tant prové de la flota d'encerclament, a les Illes la pesca de bou produeix prop del 70% dels desembarcaments, seguida de la pesca artesanal que aporta prop del 20% i, per últim, l'encerclament just per sobre del 10% (Quetglas et al., 2012; Figura III).

Amb aquesta situació, és fàcil deduir que l'estructura de comercialització dels productes de la pesca local a les Illes Balears depèn en gran part de les captures realitzades per les barques de bou.

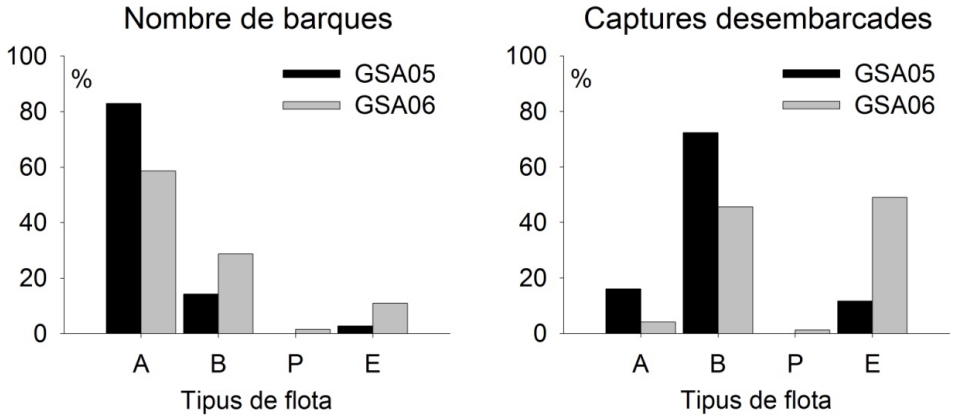


Figura III. Estructura de la flota pesquera (% de barques per tipus de flota al que pertanyen) i origen de les captures desembarcades a les subàrees geogràfiques de la Comissió General de Pesca del Mediterrani GSA5 (Illes Balears) i la GSA6 (Nord-est Península Ibèrica). A: artesanals; B: bou de fons; P: palangre; E: encerclament. Adaptat de Quetglas et al. (2012).

Aquesta flota gairebé és íntegrament local a Mallorca i Menorca i actualment hi pesquen unes trenta-set barques dedicades a la pesca de bou tant a la plataforma continental com al talús. A les Pitiüses, la flota local la composen set barques de bou, que gairebé treballen exclusivament a la plataforma continental, mentre que el talús és explotat per una mitjana de 20 barques provinents de diversos ports de la Península Ibèrica (Quetglas et al., 2012; Figura IV), regulades per un pla de pesca específic (*ORDEN APA/1728/2005, de 3 de junio, por la que se regula la actividad de los buques de arrastre peninsulares que faenan en aguas profundas de los caladeros de las islas de Ibiza y Formentera*).

Fins it tot tenint en compte les barques de bou amb port base a la Península que operen a les illes Balears, la flota de ròssec de l'Arxipèlag és molt més reduïda que a les zones properes de la costa peninsular, com també ho és l'esforç pesquer que aquestes barques realitzen (Figura V).

Aquest fet repercuteix positivament en la presència d'espècies més vulnerables i en l'estructura poblacional d'algunes de les principals espècies objectiu d'aquesta pesquera. Així, els peixos elasmobranquis, considerats altament vulnerables a l'impacte de la pesca (Stevens et al., 2000), presenten major abundància, biomassa i diversitat a les Illes Balears que a la Península Ibèrica (Quetglas et al., 2012). De la mateixa manera, la població de lluç

(*Merluccius merluccius*), espècie sobre-explotada tant a les Illes com a la Península (GFCM, 2014), a l'Arxipèlag presenta talles més grosses i un major percentatge d'individus per sobre de la talla de primera maduresa (Figura VI).

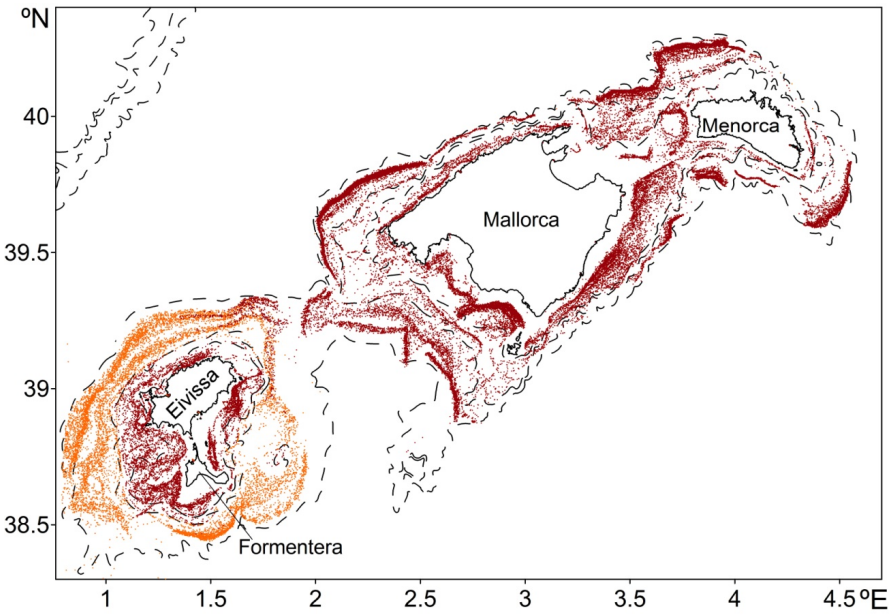


Figura IV. Mapa que mostra les senyals del *Vessel Monitoring Satellite System* (VMS) també conegut com a caixes blaves, de la flota de ròssec al voltant de les Illes Balears durant l'any 2011. En vermell es representen les senyals de la flota amb port base a les Illes Balears i en taronja les de la flota peninsular, que opera al talús de les Pitiüses. Les isòbates corresponen a 100, 200 i 800m.

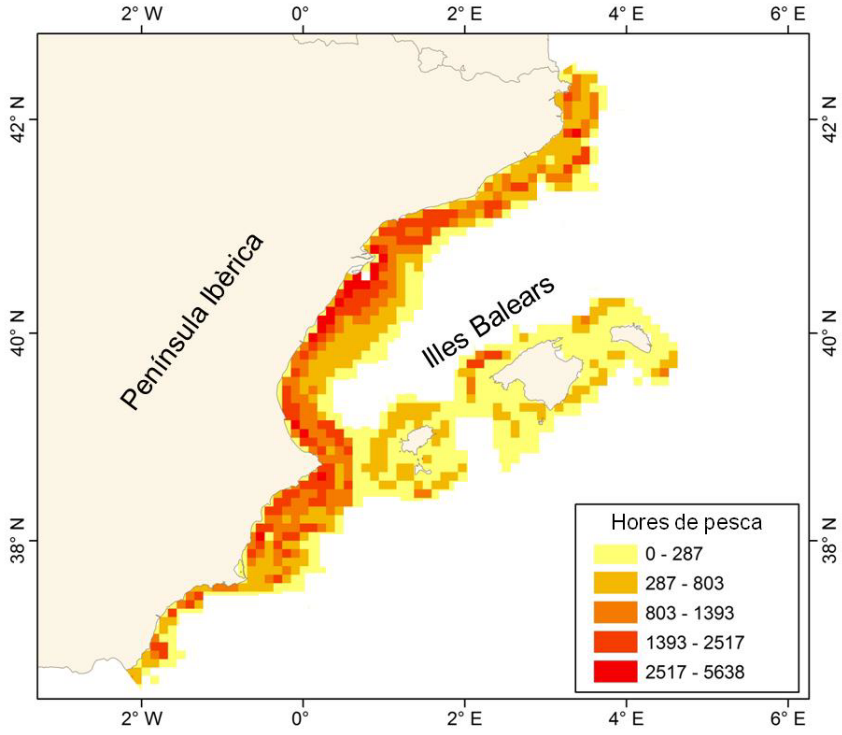


Figura V. Mapa de l'esforç pesquer realitzat per la flota de ròssec espanyola durant el període 2007-2010, estimat a partir de les senyals del *Vessel Monitoring Satellite System* (VMS). Adaptat de IEO (2012).

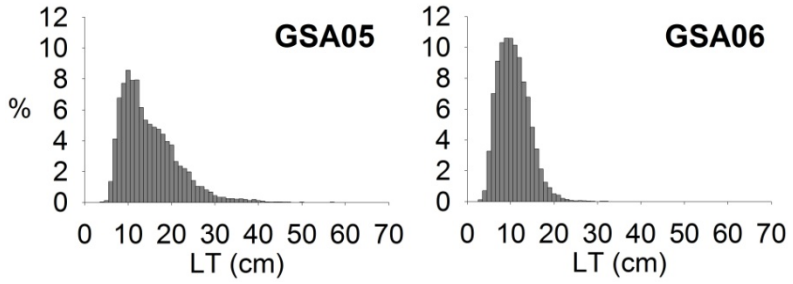


Figura VI. Distribució de talles de la població del lluç (*Merluccius merluccius*) a les Illes Balears (GSA05) i al nord-est de la Península Ibèrica (GSA06), estimada a partir de les dades obtingudes en les campanyes de recerca MEDITS. La talla de primera maduresa d'aquesta espècie és 32.7 cm de longitud total (LT) (Oliver, 1993). Adaptat de Quetglas et al. (2012).

Pel que fa al caràcter multi-específic de la pesquera de bou a les Balears, és important tenir en compte la diversitat d'estratègies de pesca que hi desenvolupa la flota de ròssec. A partir dels cinquanta metres de fondària les barques de bou exploten tant la plataforma continental com el talús, i poden arribar fins als vuit-cents metres de fondària. En aquest rang batimètric s'hi han identificat quatre estratègies bàsiques de pesca, adreçades cada una a la captura d'espècies objectiu diferents (Palmer et al., 2009). Aquestes estratègies s'identifiquen bastant bé amb les principals comunitats d'espècies i recursos demersals descrites a la plataforma continental i al talús del Mediterrani: p.ex. Massutí i Reñones (2005) a la conca occidental, Biagi et al. (2002) i Colloca et al. (2003) a la part central, i Kallianiotis et al. (2000) a la conca oriental. A continuació es resumeixen els rangs batimètrics i les principals espècies objectiu i/o categories comercials d'aquestes estratègies de pesca a les Illes Balears, atenent a les seves captures, valor de mercat i rendiment econòmic (Figura VII):

- La plataforma costanera, des de 50 fins 100 m de fondària, amb la Morralla, categoria comercial de peixos en la qual s'hi ajunten una gran diversitat d'espècies de tamany mitjà i petit (p.ex. *Trigloporus lastoviza*, *Trachinus draco*, *Scorpena notata*, *Serranus hepatus*, *Serranus cabrilla, Chelidonichtys cuculus* i *Pagellus acarne*) i individus de mida petita d'espècies més grosses (p.ex. *Scorpanea scrofa*, *Pagellus erythinus*), el calamar (*Loligo vulgaris*), el pop de roca (*Octopus vulgaris*), el moll de roca (*Mullus surmuletus*) i el gerret (*Spicara smaris*), com a principals espècies objectiu.

- La plataforma profunda, entre 100 i 250 m de fondària, on les principals espècies objectiu són el lluç (*M. merluccius*) i el gall (*Zeus faber*).

- El talús superior, entre 250 i 600 m de fondària, en el qual la principal espècie objectiu és l'escamarlà (*Nephrops norvegicus*), però on també poden ser importants els rendiments d'espècies com el lluç (*M. merluccius*), les bruixes (*Lepidorhombus* spp.), els raps (*Lophius* spp.) i la maire (*Micromesistius poutassou*).

- El talús mitjà, entre 600 i 800 m de fondària, en el qual només hi ha una espècie objectiu: la gamba vermella (*Aristeus antennatus*).

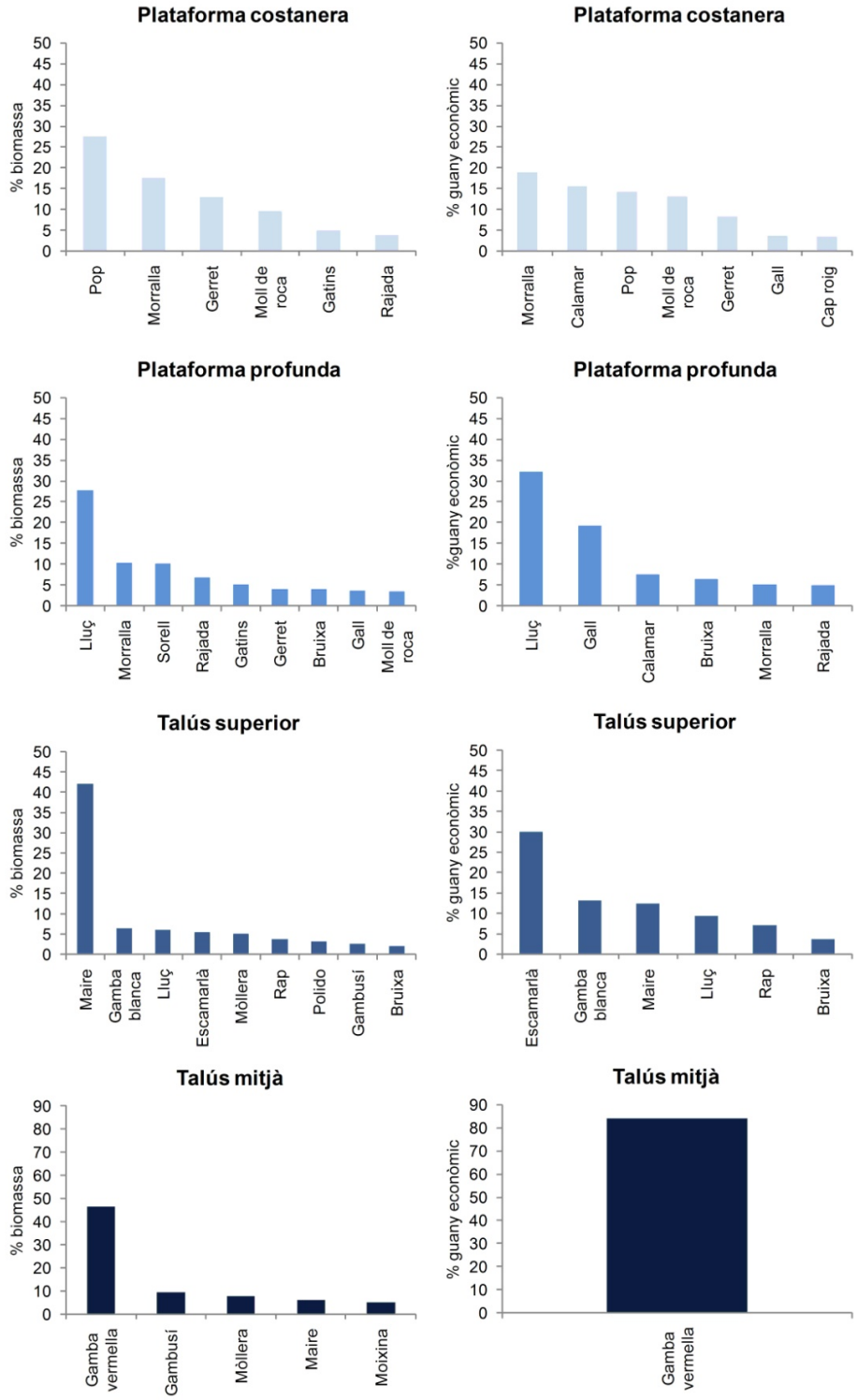


Figura VII. Principals categories comercials per estratègia de pesca de la flota de ròssec de les Illes Balears. Les categories que apareixen a cada estratègia representen més del 75% en termes de biomassa desembarcada (esquerra) i guany econòmic (dreta). Font: Fulles de venda diària per embarcació entre 2007 i 2011, facilitades per la *Organització de Productors MallorcaMar*. Plataforma costanera: 50-100 m; Plataforma profunda 100-250 m; Talús superior: 250-600 m; Talús mitjà: 600-800 m. Pop: *Octopus vulgaris*, Morralla: diverses espècies d'osteïctis, Gerret: *Spicara smaris*, Moll de roca: *Mullus surmuletus*, Gatí: *Scyliorhinus canicula*, Rajades: *Raja* spp., Calamar: *Loligo* spp., Gall: *Zeus faber*, Cap roig: *Scorpaena scrofa*, Lluç: *Merluccius merluccius*, Sorell: *Trachurus* spp., Bruixa: *Lepidorhombus* spp., Maire: *Micromesistius poutassou*, Gamba blanca: *Parapennaeus longirostris*, Escamarlà: *Nephrops norvegicus*, Mòllera: *Phycis blennoides*, Rap: *Lophius* spp., Polido: *Argentina* spp./*Chlorophthalmus agassizi*, Gambusí: *Plesionika* spp., Gamba vermella: *Aristeus antennatus*, Moixina: *Galeus melastomus*.

Aquestes estratègies de pesca són comunes a les que realitza la flota de ròssec dels ports de la costa peninsular. No obstant, una particularitat de la flota de les Illes Balears és que les barques combinen freqüentment aquestes tàctiques fins i tot durant un mateix dia, per tal de diversificar la captura (Quetglas et al 2012; Figura VIII).

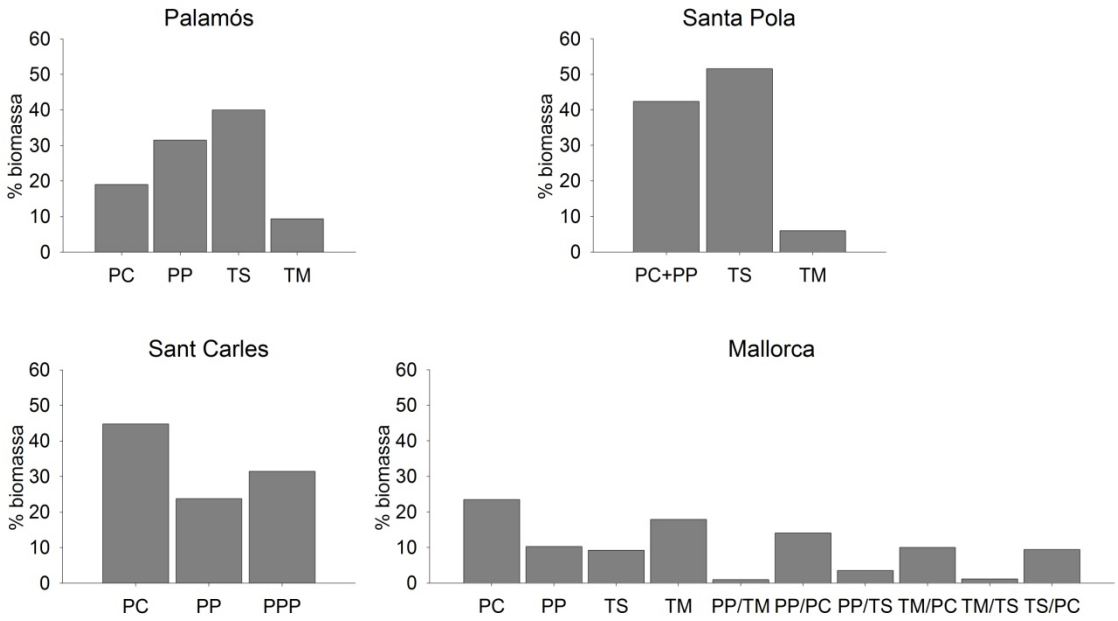


Figura VIII. Percentatge de biomassa desembarcada en les diferents estratègies de pesca de la flota de ròssec de Mallorca i de tres dels ports més importants del nord-est peninsular (Palamós, Santa Pola i Sant Carles de la Ràpita). PC: plataforma costanera; PP: plataforma profunda; PPP: plataforma profunda explotat amb bou semi-pelàgic; TS: Talús superior; TM: Talús mitjà. Adaptat de Quetglas et al. (2012).

L'estratègia a la qual la flota de les Illes Balears dedica més esforç és la que explota exclusivament el talús mitjà, amb un promig del 40% de totes les sortides diàries de pesca registrades entre 2000 i 2011. Aquesta és també l'estratègia que més beneficis econòmics dóna (40% del total), mentre que l'estratègia dedicada exclusivament a l'estrat més superficial, la plataforma costanera, és la que desembarca més captures, amb un promig del 21% de la biomassa total (Figura IX). Tenint en compte totes les estratègies de pesca en les que s'explota la plataforma continental i descomptant les categories comercials que caracteritzen el talús en els dies en què la flota ha explotat el talús i la plataforma, es pot estimar que la plataforma continental aporta fins prop del 65% de la biomassa total desembarcada. En termes de rendiment econòmic, aquest percentatge es redueix fins a gairebé el 40% del total degut al major valor econòmic que tenen les captures de crustacis del talús.

A la zona d'estudi d'aquesta tesi, el promontori Balear, les barques de bou són presents a deu ports: Pollença (una barca), Alcúdia (3), Cala Rajada (4), Portocolom (1), Cala Figuera (4), Palma (5), Andratx (8), Sóller (4), Ciutadella (4) i Maó (3) (Figura X). D'aquests, només un port, Cala Figuera, podria esser considerat un port especialitzat en l'explotació d'un sol estrat batimètric donat que les seves barques es dediquen gairebé de forma exclusiva a explotar la

plataforma continental a menys de 100m de fondària (Figura X). Tot i haver-hi barques només dedicades a una sola estratègia de pesca als altres ports, sobretot a l'estiu en què exploten principalment el talús mitjà degut a la major demanda i al preu més elevat de la gamba vermella (*A. antennatus*), moltes barques opten per seguir estratègies mixtes, les quals representen una de cada tres sortides a la mar que realitza la flota de ròssec a Mallorca.

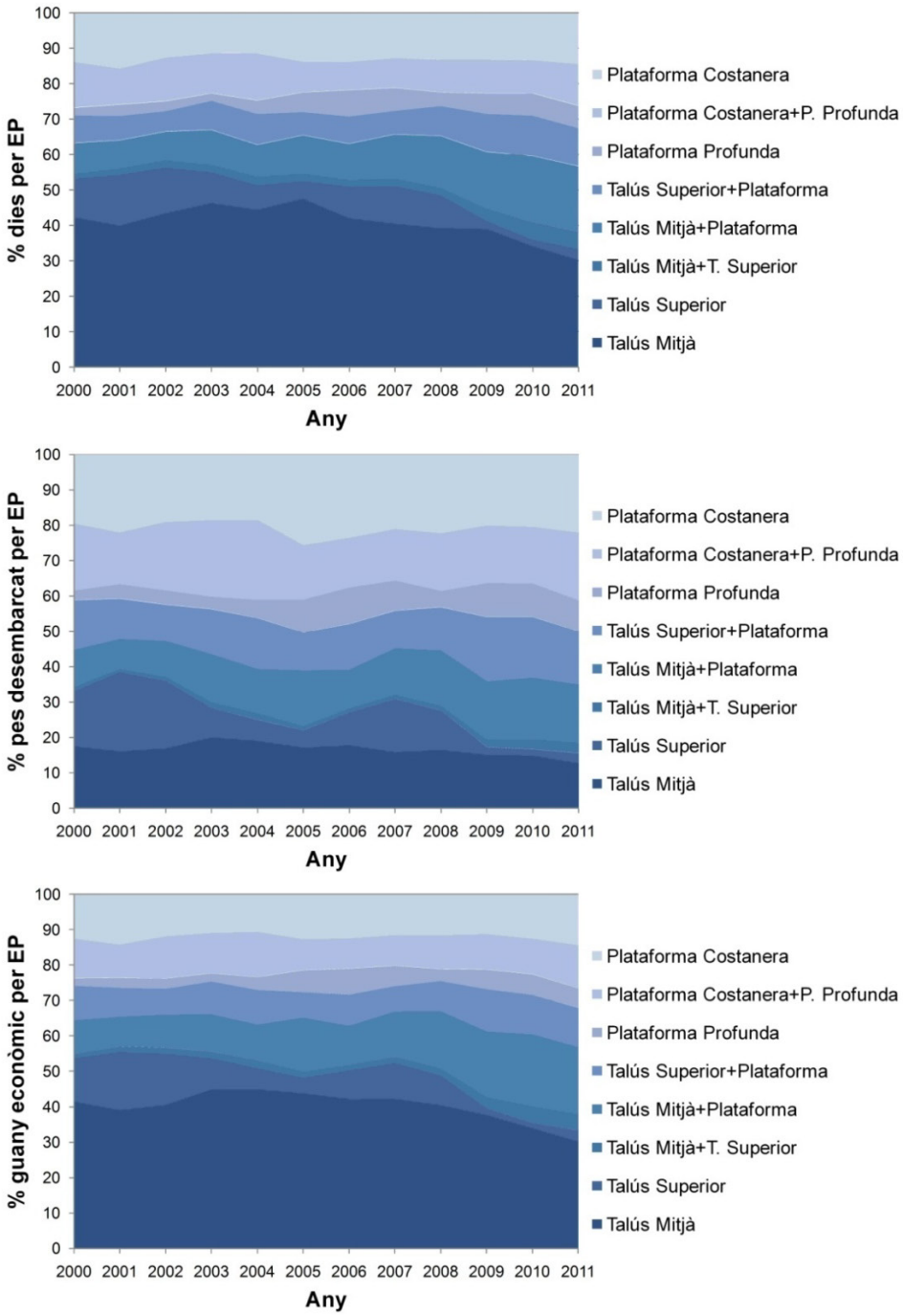


Figura IX. Percentatge de dies dedicats per la flota de ròssec de Mallorca a cada una de les estratègies de pesca (EP) detectades, i el seu percentatge de biomassa desembarcada i guany econòmic durant el període 2000-2011. Font: Font: Fulles de venda diària per embarcació entre 2007 i 2011, facilitades per OP MallorcaMar i resultats dels anàlisis de segmentació de la flota duts a terme en el marc del *Programa Nacional de Recopilación de Datos Básicos Pesqueros*, finançat per la Unió Europea.

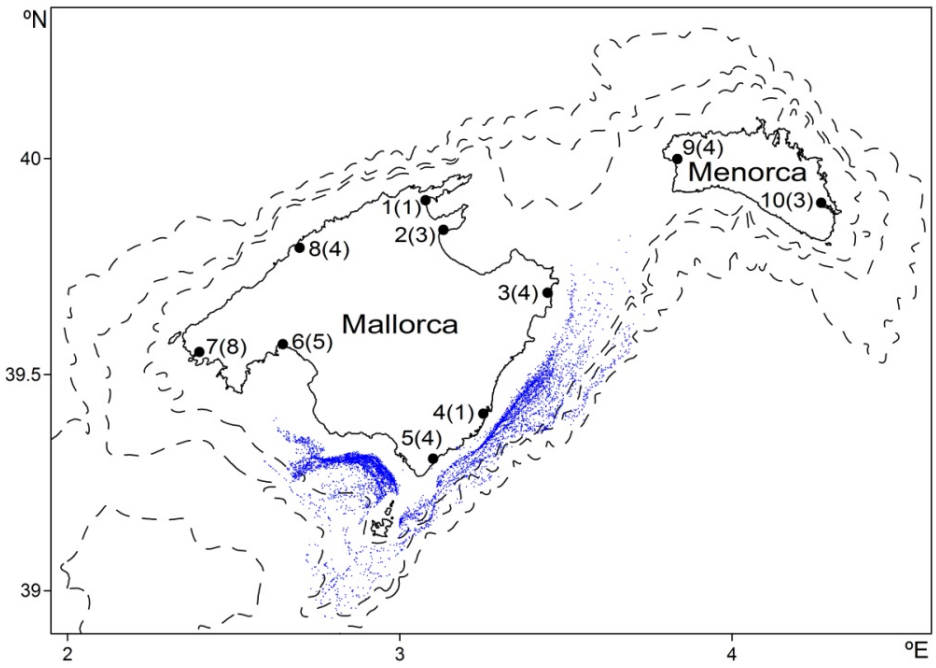


Figura X. Mapa que mostra els principals ports de Mallorca i Menorca (1: Pollença, 2: Alcúdia, 3: Cala Rajada, 4: Portocolom, 5: Cala Figuera, 6: Palma, 7: Andratx, 8: Sóller, 9: Ciutadella, i 10: Maó), amb el nombre de barques de bou indicat entre parèntesi. En blau es mostren les senyals del Vessel Monitoring System (VMS) de la flota de Cala figuera (Santanyí) durant 2011. Les isòbates corresponen a 100, 200 i 800 m.

A excepció de l'estratègia de pesca que es desenvolupa únicament al talús mitjà, que té com a objectiu i captura quasi exclusiva la gamba vermella, la resta d'estratègies de pesca generen captures multi-específiques, amb rendiments econòmics molt repartits entre un gran nombre d'espècies i/o categories comercials, que augmenten a mesura que disminueix la profunditat. El cas extrem és la plataforma costanera, en què la principal categoria comercial quant a guanys econòmics, i segona quant a biomassa desembarcada, és la Morralla, en la qual s'hi arrepleguen fins a prop de 60 espècies de peixos osteïctis cap de les quals és una espècie objectiu per si sola, sinó que se es tracta d'espècies 'by-catch', que ajuntades en una sola categoria, s'han convertit en una 'espècie' objectiu de la pesquera (Figura VIII, Figura XI).

Aquesta varietat de les captures de la flota de ròssec en els caladors de la plataforma continental es pot explicar per la diversitat d'hàbitats que hi ha en aquests fons, palesa des dels primers estudis científics sobre les comunitats bentòniques de les Illes Balears. El 1934, a partir dels resultats d'una de les primeres campanyes científiques de prospecció de la plataforma i marge continentals, Fernando de Buen assenyalà la presència i importància de les fàcies que anomenà 'cascajo' en la plataforma costanera, en què agrupà diversos tipus de fons d'algues vermelles, i els fons de crinoïdeus (*Leptometra phalangium*) i braquiòpodes (*Gryphus vitreus*) en la plataforma profunda.

Les condicions oceanogràfiques de les aigües que envolten les Illes Balears afavoreixen la presència d'aquests hàbitats. L'absència de rius a

l'Arxipèlag redueix la quantitat de sediments terrígens, per la qual cosa els fons de fang són molt escassos a la plataforma costanera, en la qual predominen els d'origen biogènic (Canals i Ballesteros, 1997). La majoria dels sediments de la plataforma continental estan formats per sorres i graves amb alts percentatges de carbonats (Acosta et al., 2002). Aquesta absència de rius també limita l'aportació de nutrients, i fa que les aigües de les Balears siguin més oligotròfiques que les de zones adjacents de la costa peninsular i les del Golf de Lleó (Estrada, 1996; Bosc et al., 2004). L'absència de sediments terrígens i l'oligotròfia fa que augmenti la transparència de les aigües, i permet que la llum arribi a major fondària que a la costa continental. Per això, les fàcies d'algues vermelles es poden desenvolupar en la plataforma costanera fins als 90 m de profunditat (Ballesteros, 1992, 1994; Barberà et al., 2012). D'altra banda, els canals entre les Illes i entre l'Arxipèlag i la Península Ibèrica, que determinen la hidrodinàmica marina de la Mediterrània occidental i són importants per l'intercanvi d'aigües entre les sub-conques Balear, al nord de l'Arxipèlag, i Algeriana al sud, podrien afavorir la presència de determinats tipus de fons. Aquest seria el cas dels fons de crinoïdeus i els de braquiòpodes, sovint relacionats amb àrees de forts corrents en la plataforma profunda i marge continental (Laborel et al., 1961; Emig, 1987; Pérès, 1985).

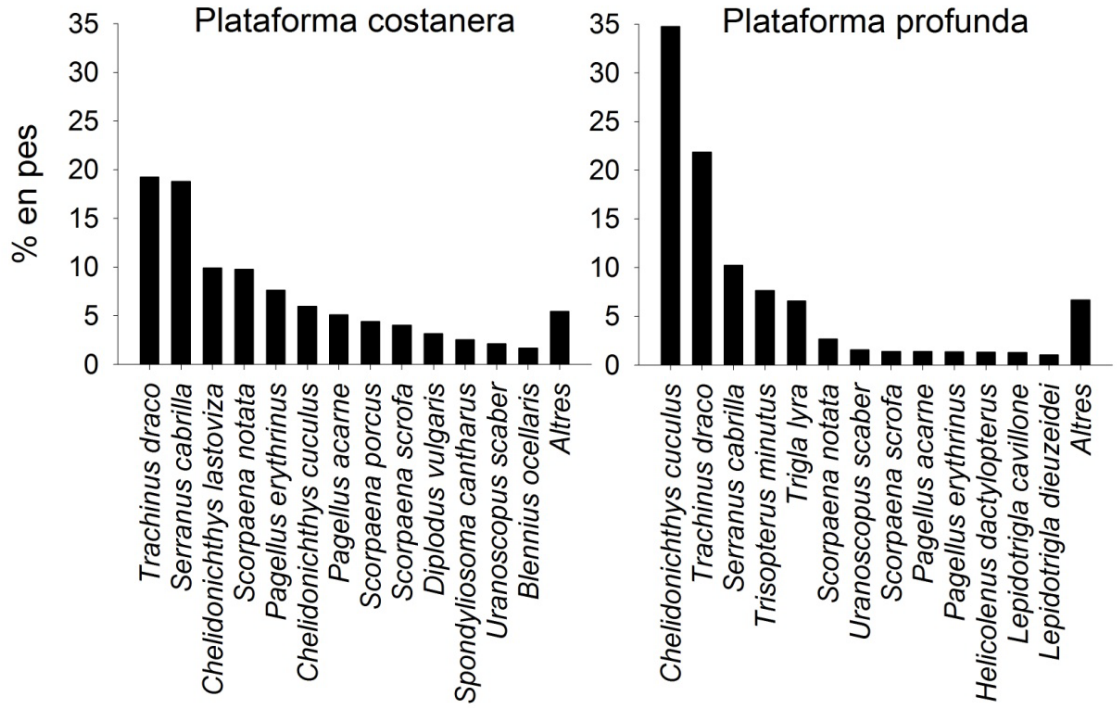


Figura XI. Composició dels desembarcaments de la categoria comercial Morralla capturada per la flota de ròssec de Mallorca en la plataforma costanera (<100 m) i profunda (100-250 m). Promig pel període 2008-2010. Font: Dades recopilades durant els mostratges periòdics que realitzen observadors científics a bord, en el marc del en el marc del Programa Nacional de Datos Básicos Pesqueros .

Els caladors tradicionals de la flota de ròssec de les Illes Balears coincideixen amb aquests hàbitats bentònics. Molt especialment en el cas del 'cascajo', del que de Buen (1934) explicà "*Dejando hacia tierra arenas limpias,*

de granos con grosor diverso, o praderas vegetales, al descender a niveles inmediatos nos encontramos en la bahía de Palma, en toda la costa Sudoeste y, en general, en las Baleares, con una formación extremadamente variada y muy rica en invertebrados, a la par de la escasez, rareza y, en ocasiones, falta de peces. Incluimos a la totalidad de esta formación con el nombre de cascajo...". Entre aquests fons, Fernando de Buen en defineix diverses variants com el '*cascajo orgánico*' amb domini d'algues vermelles calcàries i actualment conegut com maërl, els fons "d'*avellanó"* dominats per algues vermelles de la família Peyssonneliaceae, els fons d'herba col (*Laminaria rodriguezii*), i els fons d'*herba crespa* o *herba torta*, on domina l'alga vermella tova *Osmundaria volubilis.*

Aquestes fàcies són molt comunes i a més presenten cobertures i biomasses molt elevades. Fins i tot, com és el cas dels fons d'*avellanó*, més elevades que les dels fons litorals dominats per algues del Mediterrani occidental (Ballesteros, 1994). Com passa en altres àrees, la producció primària d'alguns d'aquests fons podria esser important pel sosteniment de les comunitats animals que els habiten. Aquest seria el cas dels fons de *Phyllophora antarctica* a l'Antàrtida, on aquesta alga, la qual té un parent molt abundant als fons d'algues vermelles de Balears, la *P. crispa* (Ballesteros, 1992), suposa una font d'aliment per a nivells tròfics superiors durant l'hivern, que els permet fer front a l'estacionalitat de recursos que hi ha a aquella zona (Norkko et al., 2004).

Actualment, la majoria dels stocks de recursos pesquers demersals avaluats periòdicament al Mediterrani són explotats per sobre del seu rendiment màxim sostenible (Vasilakopoulos et al., 2014). Les Illes Balears no en són una excepció, i el moll de roca (*M. surmuletus*) i el lluç (*M. merluccius*), les dues espècies objectiu de la flota de ròssec en la plataforma continental que s'avaluen de manera periòdica, presenten símptomes de sobrepesca (GFCM, 2014). Malgrat el clar caràcter multiespecífic d'aquesta pesquera, no es té informació sobre l'estat d'explotació d'altres espècies de plataforma. Les altres avaluacions que es fan són d'espècies de talús, més concretament la gamba vermella (*A. antennatus*) i l'escamerlà (*N. norvegicus*).

Les Illes Balears, amb una distància al voltant les 40 i 90 milles des de les Pitiüses i Mallorca-Menorca a la Península Ibèrica, respectivament, són una de les àrees insulars més allunyades del continent a la Mediterrània occidental. Un aïllament que també és palès en termes de profunditat, ja que l'Arxipèlag està separat de la costa peninsular per fondàries de fins a 2000 m, exceptuant el canal d'Eivissa en què la fondària arriba als 800 m (Figura XII). És de suposar que aquestes distàncies i profunditats actuen com a barreres efectives entre els ecosistemes demerals de les Illes i els de la Península, almenys pel que fa referència als individus adults d'espècies necto-bentòniques que habiten la plataforma continental.

Aquest aïllament de les Illes Balears podria tenir una part positiva pel que fa a la conservació dels recursos i ecosistemes demersals. A excepció del talús de les Pitiüses, en el qual treballen barques de bou provinents de ports peninsulars (García-Rodríguez i Esteban, 1999) i alguns altres vaixells també de la Península Ibèrica que puntualment es desplacen a Mallorca i Menorca per

pescar amb nanses (García-Rodríguez et al., 2000), la flota pesquera professional que explota aquests ecosistemes i recursos insulars és bàsicament local. Està menys desenvolupada que la flota dels ports peninsulars propers, sobretot pel que fa referència a les barques de bou, tant pel que fa referència al número d'embarcacions com a la seves dimensions (Quetglas e al., 2012), la qual cosa fa que l'esforç pesquer a les Illes Balears sigui menor que el de zones peninsulars adjacents. Per contra, aquest aïllament dels ecosistemes i recursos demersals insulars podria ser un problema davant un eventual col·lapse de les seves pesqueres, ja que per a la seva recuperació, al menys pel que fa a la plataforma continental, no es podria comptar amb el suport que donaria una possible transferència de fases larvàries pelàgiques, provinents dels ecosistemes peninsulars més productius. Malgrat s'hagi suggerit que durant els anys en què el Front Balear, que flueix pel nord de l'Arxipèlag, es veu reforçat pel bloqueig de la Corrent del Nord en el Canal d'Eivissa (Figura XIII), podria haver-hi una certa aportació d'individus d'espècies demersals, com el lluç (*M. merluccius*), des de la costa Peninsular i les Illes Balears (Massutí et al., 2008), tot i que les evidències científiques encara són escasses.

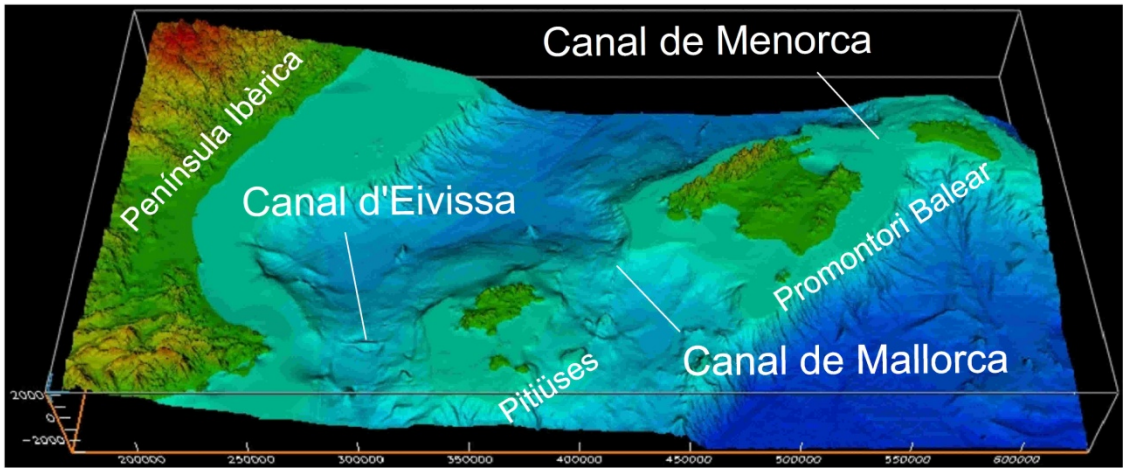


Figura XII. Mapa batimètric de les Illes Balears i la costa adjacent de la Península Ibèrica. S'indiquen els tres canals més importants de l'Arxipèlag: els d'Eivissa i Mallorca, on la profunditat mínima es situa al talús mitjà, entorn als 800 i 600 m, respectivament, i el de Menorca, on la profunditat mínima està entorn als 70 m. Adaptat de Acosta (2005).

Les mesures de gestió que s'apliquen a la pesca de bou de les Illes Balears, com per exemple la regulació horària de l'activitat (es pot pescar 5 dies a la setmana, realitzant sortides de fins a 12 hores diàries), la prohibició de pescar a menys de 50 m de fondària, talles mínimes per a determinades espècies i el recent canvi de la geometria de la malla del cop, de ròmbica a quadrada, són les mateixes que les de la Península Ibèrica. Les Illes Balears és la comunitat autònoma de l'Estat Espanyol amb major nombre d'àrees marines protegides (fins a vuit; al Parc Nacional Marítim-Terrestre de l'Arxipèlag de Cabrera s'hi han d'afegir les reserves marines de la Badia de Palma, del Nord de Menorca, dels Freus d'Eivissa i Formentera, del Migjorn de Mallorca, de l'Illa del Toro, de les Illes Malgrats i del Llevant de Mallorca), les quals se situen

principalment en àrees litorals i no repercuteixen en la pesquera de ròssec. Tan sols el Parc Nacional de Cabrera i la reserva del Migjorn de Mallorca inclouen caladors tradicionals de les barques de bou, que en el cas de Cabrera van ser tancats a aquesta modalitat de pesca des de la creació del Parc, a principis dels anys noranta, mentre que en la reserva del Migjorn es permet la pesca de bou, amb algunes limitacions.

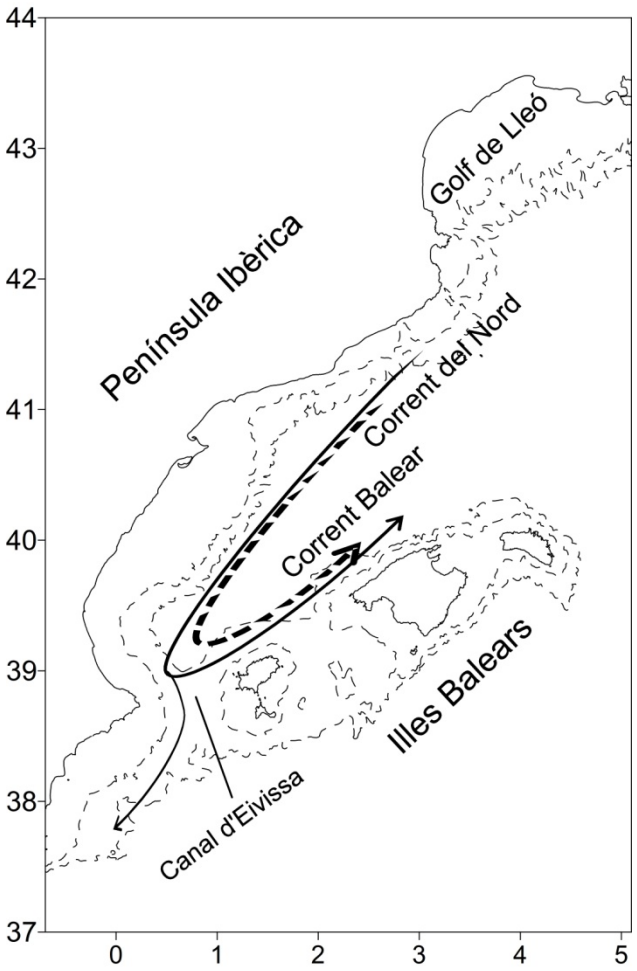


Figura XIII. Mapa que representa les principals corrents de talús al Nord-est de la Península Ibèrica i les Illes Balears durant primavera-estiu, després d'un hivern suau (línea continua) i després d'un hivern fred (línea discontinua). Les isòbates que es mostren són les de 200 i 1000 m de profunditat. Adaptat de Massutí et al. (2008).

Llevat d'aquestes àrees marines protegides, i d'algunes zones amb cables submarins en les quals no es permet la pesca amb arts de ròssec, en la resta dels fons potencialment explotables per les barques de bou de les Illes Balears no es contempla cap mesura de gestió espaial, per a la protecció dels seus hàbitats bentònics d'especial interès, alguns dels quals han estat recentment declarats com a hàbitats protegits per a la normativa europea i espanyola (coral·ligen i maërl), que prohibeix la pesca amb arts de ròssec sobre aquests fons. La informació científica necessària per a poder desenvolupar aquest tipus de gestió, basada en el cartografiat de les biocenosis bentòniques i l'activitat de la flota de ròssec, és escassa (p.ex. Canal de Menorca; Barberà et al., 2012). Aconseguir aquesta informació, així com esbrinar quines són les relacions entre aquestes biocenosis i els organismes que s'hi troben associats, són punts clau per tal d'intentar compatibilitzar la sostenibilitat de la pesquera de ròssec amb

la conservació del medi marí i els seus recursos, un dels principals reptes actuals de la gestió de la pesca de bou a les Illes Balears.